2-1-1974

Stormwater Runoff Quality For Urban And Semi-Urban/ Rural Watersheds

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TECHNICAL REPORT NO. 43

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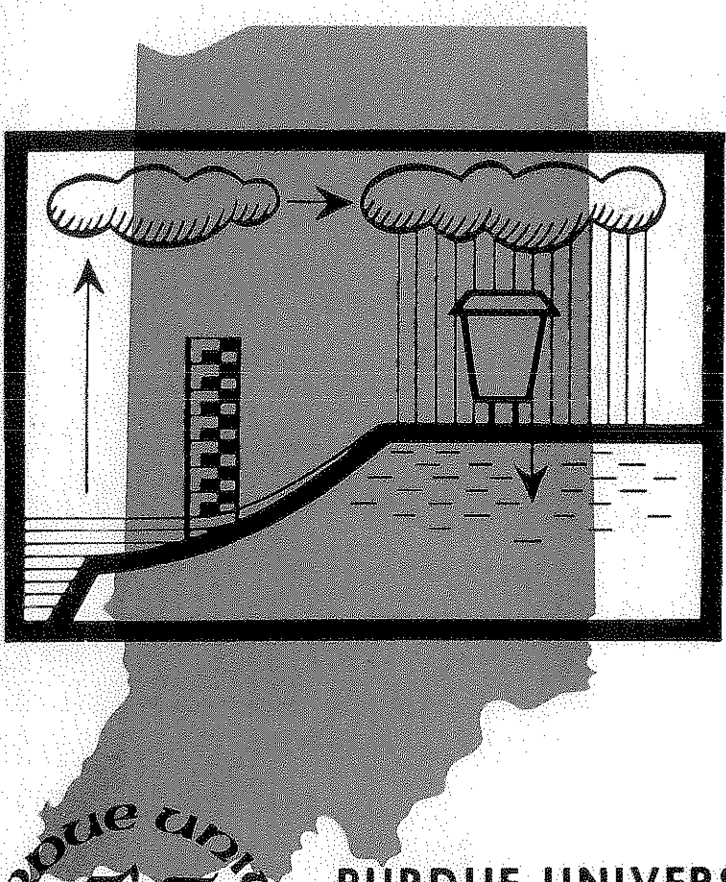

by

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FEBRUARY 1974

PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
WEST LAFAYETTE, INDIANA

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This is a partial completion report of OWRR Project No. C-3277-IND (Agreement No. 14-31-0001-3713) entitled "Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities"

Purdue University

Department of Environmental Engineering

West Lafayette, Indiana

The work upon which this report is based was supported in part by funds provided by the United States Department of Interior, Office of Water Resources Research, as authorized by the Water Resources Act of 1964. (PL 88-379).

Technical Report No. 43

Purdue University Water Resources Research Center

West Lafayette, Indiana

February 1974

ACKNOWLEDGEMENTS

The author is indebted to Mr. Dave Cochran and Mr. Nick Coburn for their technical assistance in the installation and operation of sampling equipment and to Mrs. Martha Beach for her advice regarding the purchase of sampling equipment. The author is grateful for the financial support from the Office Of Water Resources Research which made the study possible.

The work upon which this report is based was supported by funds provided by the United States Department of the Interior, Office of Water Resources Research, as authorized by the Water Resources Research Act of 1964 (P.L. 88-379) and is part of the Title II Project C-3277 entitled "Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities".

Grant No. 14-31-0001-3713

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ABSTRACT

McElroy, Felix T. R.. M.S.C.E., Purdue University, May 1973. Development of Sampling Methodology for Monitoring Stormwater Runoff Quality for Urban and Semi-Urban/Rural Watersheds in the West Lafayette, Indiana Area. Major Professor: John M. Bell.

In reviewing the literature it was found that the most cited parameters for determining the quality of stormwater runoff are BOD, suspended solids, and total coliforms. In several studies a great deal of emphasis was placed on determining the effect of increased urbanization. Another general topic was that of first flushing of stormwater drainage systems and those parameters which may effect its magnitude.

The investigation of stormwater runoff quality was begun in conjunction with the Water Resources Research Center of Purdue University in accordance with a proposal entitled, "Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities". Funding was made possible by the Water Resources Research Act of 1964, Public Law 88-379.

Samples of stormwater runoff from an urban and semi-urban/rural watershed were collected at established gaging-sampling stations. The urban watershed is a 29-acre fully developed residential area. The semi-urban/rural watershed of 292 acres

is 35 to 45 percent residential, 25 percent rural farmland.

The sampling equipment consisted of a Sentry Automatic Sequential Composite Sampler, a floatless liquid level control, an AC/DC converter and an isolation transformer. The Sentry sampler consists of a peristaltic pump and a programmer which can be pre-set by means of movable keys on a timing drum which moves one revolution per hour.

The type of sample used to determine the quality of run-off was a semi-continuous composite sample. The sampling frequency was one sample per half-hour and a 1000 ml sample volume was used. Sampling was carried out over the entire duration of the storm in order to determine the effect of flow on the pollution parameters. The analyses performed on all samples were BOD and suspended solids. Total and fecal coliforms analyses were performed on only a few samples. Samples were collected during four storms at the urban water-shed and four storms at the semi-urban/rural watershed.

A preliminary investigation of the quality of dry weather flows indicated that little pollution was present.

The peak BOD concentrations in the runoff from the urban and semi-urban/rural sampling stations ranged from 11.0 to 44.5 mg/l and from 3.0 to 7.0 mg/l respectively while sus-pended solids concentrations ranged from 62 to 250 mg/l for the urban sampling station and 6 to 170 mg/l for the semi-urban/rural sampling stations. The total and fecal coliform counts for the runoff from both watersheds ranged from 930 to to 240,000 and from 430 to 93,000 organism/ml, respectively.

A "first flush" of suspended solids and BOD was exhibited at the urban sampling station while no "first flush" of BOD and only a very small flush of suspended solids was apparent at the semi-urban/rural station.

Mass emission pollutographs of BOD and suspended solids were found for both stations. It was found that the concentration and flow both affected the shape of the pollutograph. The flow hydrograph had a much more dramatic effect on the shape and magnitude of the pollutograph. The sampling frequency had a measurable effect on the peak of the mass emission pollutograph.

In order to compare the two watersheds, the unit "pounds per day per acre - MGD" was used to reduce the stormwater runoff quality data from the watersheds to an equal basis. The stormwater runoff from the semi-urban/rural watershed had suspended solid and BOD values ranging from .14 to 4.3 lb/day/acre - MGD and from .07 to .14 lb/day/acre - MGD, respectively. The urban watershed had BOD values ranging from 7 to 24 lb/day/acre - MGD and suspended solids ranging from 2 to 8 lb/day/acre - MGD.

INTRODUCTION

Public concern and action in regards to pollution of the rivers and streams in urban and industrial areas has been reflected in improved technology and legal procedures to effect the elimination or reduction of water pollution from well-defined sources. Now that this problem has been more or less solved, the current problem is the protection of the quality of the streams in the face of stormwater pollution resulting from urbanization, industrial expansion, and agricultural practices.

Stormwater runoff is a diffuse source rather than a point source. As such, it is not readily identified, characterized, and quantified. For years stormwater has been ignored as a source of pollutants. It can be expected that in the near future the quality of stormwater will deteriorate sufficiently to require treatment in order to eliminate its pollutional effect on our lakes and streams.

The use of the land has a direct effect upon the quality of water draining from the land. Stormwater has been deliberately utilized to dilute sanitary and industrial wastewater in design of sanitary and combined wastewater collection systems. Urbanization affects both the hydraulic and pollutional characteristics of a watershed. Changes in land use may, therefore, affect not only the quantitative yield characteristics of a drainage basin but the quality of its stormwater.

Better knowledge of the amount of diffuse pollution is a current need as a logical prerequisite to an understanding of its future role in stream pollution abatement. The amount and nature of stormwater runoff is desirable information prior to commitment of extensive financial resources for construction and operation of separation and/or treatment facilities.

With the increasing quality standards for wastewater effluents and the increasing efficiency of waste treatment plant operation, it is easy to conclude that this form of pollution may soon become the major degrading factor of the streams.

The main objective of this study was to outline sampling procedures to be used so as to best characterize pollutants in stormwater runoff, from two types of watersheds: 1) an urban watershed and 2) a combined semiurban and rural watershed; hereinafter denoted as the semi-urban/rural watershed. Other objectives were to characterize and quantify the pollution in stormwater runoff, compare the runoff from the two watersheds, examine effects of first flushing, and measure the effects of varying sampling frequency of the mass emission pollutograph.

The urban watershed that was used in this study is a 29-acre, fully developed, residential area. This area is 38 percent impervious. The semi-urban/rural watershed, which is made up of a rural and a semiurban watershed, is 292 acres and only partially developed.

The investigation of runoff pollution was begun in conjunction with the Water Resources Research Center of Purdue University in accordance with a proposal entitled: "Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities". Funding was made possible by the Water Resources Research Act of 1964 - Public Law 88-379. The stormwater runoff from these watersheds were monitored and sampled at similar stations. The gaging-sampling station contains a stage and rainfall recorder, a raingage, a flow measuring device, and an automatic composite sequential sampler.

Analyses were performed on composite samples taken over half hour intervals at the two stations. The analyses used in this study were chosen on the basis of previous studies. They were BOD, suspended solids, and total and fecal coliforms.

REVIEW OF THE LITERATURE

Introduction

Dunbar and Henry (1) possibly best-stated the reason for studying stormwater runoff in the following passage:

> "The contribution to stream or lake pollution by untreated stormwater can be considerable. Insofar as suspended solids are concerned, untreated stormwater runoff very easily can contribute a greater amount than would be supplied by the raw sewage of a municipality possessing no treatment facilities. On the other hand, BOD, and especially coliform contributions, from untreated sanitary sewage, greatly exceed that which would normally be brought down by stormwater runoff."

Once even partial treatment has been carried out, however, the upper limits of BOD concentrations in stormwater runoff begin to assume much greater relative importance when compared with residual BOD values in the partially treated plant effluents.

Although the probable overall annual contribution of pollution by the discharge of stormwater runoff is relatively small except in the matter of suspended solids, it must be borne in mind that these loads are being applied in intermittent slugs during storm periods. This results in the disruption of the self purification of the stream.

Biochemical, Chemical, and Physical Characteristics of Stormwater Runoff

General

The major concern of pollution control agencies has been the control of pollution from discrete sources. Now that this problem has been more or less controlled, interest in pollution from diffuse sources is growing as can be seen by the increasing number of studies being performed in this area.

Studies performed at the Robert A. Taft Sanitary Engineering Center have yielded valuable information concerning stormwater runoff from a suburban area of Cincinnati. Weibel, et al (2, 3, 4, 5) found that suspended solids ranged from 5-1200 mg/l with an average concentration of 227 mg/l; volatile-suspended solids ranged from 1-290 mg/l, with an average of 57 mg/l; COD values ranged from 20-610 mg/l with an average of 111 mg/l; and BOD values ranged from 1-173 mg/l with an average of 17 mg/l.

Palmer (6, 7) investigated the quality of stormwater runoff resulting from low intensity storms in the Detroit area. The first study, which was performed in 1949, yielded the following ranges: Total solids: 310-914 mg/l; Total volatile solids: 136-414 mg/l; and, BOD: 96-234 mg/l. The second study, performed in 1960, yielded means for two storms.

The means for suspended solids were 213 and 102 mg/1; the means for volatile suspended solids were 121 and 38 mg/1.

Angino, et al (8) sampled stormwater runoff flowing through Naismith Ditch at Lawrence, Kansas. He reported total solids ranging from 344 to 4920 mg/1 with median and mean values of 759 mg/1 and 536 mg/1, respectively. Total volatile solids ranged from 22 to 733 mg/1, with median and mean values of 111 mg/1 and 149 mg/1, respectively. Suspended solids ranged from 0 to 4660 mg/1, with median and mean values of 36 mg/1 and 360 mg/1, respectively. BOD values ranged from 4.6 to 12.3 mg/1, with median and mean values of 6.6 mg/1 and 6.9 mg/1, respectively. COD values ranged from 11 to 69 mg/1 with median and mean values of 29 mg/1 and 33 mg/1, respectively.

Burm, et al (9) reported on constituents found in stormwater runoff from a watershed in Ann Arbor, Michigan. The annual mean value for BOD, suspended solids, and volatile suspended solids were 28 mg/1, 2,080 mg/1, and 218 mg/1, respectively. The maximum value observed for BOD, suspended solids, and volatile suspended solids were 62 mg/1, 11,900 mg/1, and 570 mg/1, respectively.

A research project performed by AVCO Economic Systems Corporation in conjunction with the Federal Water Quality Administration (10) reported on the stormwater runoff quality from watersheds in Tulsa, Oklahoma. The mean value for

BOD was 11.8 mg/l, while the values ranged from 8 to 18 mg/l. COD values ranged from 42 to 138 mg/l with a mean of 85.5 mg/l. The ranges for total solids and suspended solids were 199 to 2242 mg/l and 84 to 2052 mg/l, respectively. The means for these parameters were 545 mg/l and 367 mg/l, respectively.

Another research project performed by the Envirogenics Company in conjunction with the Environmental Protection Agency (11) dealt with the quality of urban stormwater runoff from Sacramento watersheds.

The reported ranges for suspended solids, volatile suspended solids, BOD, and COD were 3 to 211 mg/l, 3 to 211 mg/l, 39 to 274 mg/l, and 21 to 176 mg/l, respectively.

In a report by the Public Health Service (12) stormwater runoff from two urban areas, Oakland, California, and Washington, D.C. was analyzed. The mean values for the Oakland area for BOD and suspended solids were 59 mg/l and 203 mg/l with ranges of 13 to 153 mg/l and 60 to 1120 mg/l, respectively. Samples from this area were also examined for total solids and total volatile solids yielding mean values of 400 mg/l and 144 mg/l, respectively; and ranges of 132 to 1327 mg/l and 83 to 291 mg/l, respectively. Stormwater runoff from the Washington, D.C. watersheds were examined for BOD and suspended solids. The results yielded means of 126 mg/l and 2,100 mg/l, respectively, and ranges of 6 to 625 mg/l and 26 to 36,250 mg/l, respectively.

Bryan (13) has given results from a study of stormwater runoff from urban watersheds in the Durham, N.C. area. BOD, COD, total solids, and total volatile solids ranged from 2.2 to 238 mg/l, 40 to 660 mg/l, 274 to 13,900 mg/l, and 20 to 1110 mg/l, respectively. The means for these same parameters were 31.3 mg/l, 224 mg/l, 3930 mg/l, and 426 mg/l, respectively.

Pravoshinsky (14) reported results of a study performed in the urban area of Minsk, Russia. He found that the BOD and suspended solids ranged from 12.5 to 145 mg/l and 450 to 5000 mg/l, respectively. When "streetwash" runoff was examined, he found the BOD and suspended solids to vary between 6.1 mg/l and 223 mg/l, and 30 mg/l and 8000 mg/l, respectively.

Cleveland, et al (15) examined stormwater runoff quality parameters in the Tulsa area. He found that the mean values of BOD, COD, total solids, and total volatile solids for several storms ranged from 6.0 to 8.6 mg/l, 32 to 65 mg/l, 671 to 1029 mg/l, and 230 to 477 mg/l, respectively.

Wilkinson (16) studied stormwater runoff from a 611-acre housing estate in Oxhey, England. The mean values for BOD and suspended solids were 7.0 mg/l and 194 mg/l, respectively. The maximum values found for the two parameters were 100 mg/l and 2045 mg.1, respectively.

Brownlee, et al (17) reported on the quality of urban stormwater runoff from Lubbock, Texas watersheds. The ranges for total solids, total volatile solids, suspended solids, suspended volatile solids, and BOD were 80 to 3150 mg/1, 20 to 1605 mg/1, 52 to 2488 mg/1, 20 to 1268 mg/1, and 10 to 72 mg/1, respectively. The means for these parameters were 900 mg/1, 252 mg/1, 530 mg/1, 145 mg/1 and 25 mg/1, respectively.

The quality of stormwater runoff in the Los Angeles Flood Control District was the subject of several studies performed by the Water Conservation Division of Los Angeles (18, 19). Studies were performed during the periods 1932-34, 1957-58, 1962-63, and 1967-68. The mean values of BOD for the four studies were 6.9 mg/1, 8.2 mg/1, 16.1 mg/1, and 9.1 mg/1, respectively. The mean values for suspended solids were 7330 mg/1, 1534 mg/1, 2909 mg/1, and 1013 mg/1, respectively.

In a study performed on three watersheds in the West Lafayette, Indiana area, Schulz (20) found that the mean BOD concentration in the stormwater runoff from the urban, semi-urban, and rural drainage areas was 36 mg/1, 10 mg/1, and 4 mg/1, respectively. The mean COD concentration in the stormwater from the urban, semi-urban, and rural watersheds was found to be 140 mg/1, 72 mg/1, and 14 mg/1, respectively. The mean suspended solids concentration in the runoff from each of the three areas was found to be: 1) 224 mg/1 from the urban area; 2) 955 mg/1 from the semi-urban area; and

3) 244 mg/l from the rural area. The high concentration of suspended solids in the runoff from the semi-urban watershed appeared to be due to excavation and land-grading operations carried on in the area as a result of continuing development.

Weidner, et al (21) studied the quality of rural stormwater from three areas near Coshocton, Ohio. Two of the areas were in a wheat crop but had different management practices. The third area was an apple orchid. The stormwater runoff from these areas were examined for the total solids, BOD, and COD. The means for these parameters for each area varied with the type of watersheds. The ranges for these means were: Total solids, 500 to 575 mg/l; BOD, 2.9 to 8.4 mg/l; COD, 40 to 80 mg/l.

Weibel, et al (4) examined the stormwater runoff from a 1.45-acre cultivated field in winter wheat near Coshocton, Ohio. The field was contoured plowed and had adequate fertilization and pest control. The ranges for suspended solids, COD, and BOD were 5 to 2074 mg/l, 30 to 159 mg/l, and 0.5 to 23 mg/l, respectively, with mean values of 313 mg/l, 79 mg/l, and 7 mg/l, respectively.

Other studies (22) have been performed in Toronto, Welland (Canada), Stockholm, Moscow, Leningrad, Sheffield (England), Heywood (England), Pretoria (South Africa), and Springfield, Missouri. The results of these studies are presented in Tables 1 and 2 along with a summary of studies previously discussed.

Table 1

Physical Characteristics of Stormwater

Location	Type of Area	Source	Total Solids Range	Total Solids Mean	Volatile Solids Range	Volatile Solids Mean	Suspended Solids Range	Suspended Solids Mean	Vol. Sus. Solids Range	Vol. Sus. Solids Mean
Cincinnati	Suburban	2,3,5					5 - 1200	227	1 - 290	57
Detroit	Urban	6						213		121
(2 storms)								102		38
Coshocton,	Rural	21								
Ohio			(500 - 575)*							
Lawrence,										
Kansas	Urban	8	344 - 4,920	536	22 - 733	149	0 - 4460	360		
Detroit	Urban	7	310 - 914		136 - 414					
Coshocton,										
Ohio	Rural	4					5 - 2074	313		
Ann Arbor	Urban	9	11,900 (Max)	2080	570 (Max)	218				
Tulsa	Urban	10	199 - 2,242	545			84 - 2052	367		
Sacramento	Urban	11							3 - 211	
Washington, D.C.	Urban	12	26 - 36,250	2100						
Oakland	Urban	12	132 - 1,327	400	83 - 291	144				
Durham, N.C.	Urban	13	274 - 13,900	3930	20 - 1,110	426				
Toronto	Urban	22					150 - 430			
Welland,										
Canada	Urban	22		332				58		
Stockholm	Urban	22	30 - 3,000	309						
Moscow	Urban	22	1,454 (Max)							
Leningrad	Urban	22					263 - 1335			
Sheffield, Eng.	Urban	22								
Heywood, Eng.	Urban	22					180 - 2350			
Minsk (Russia)	Urban	14					450 - 5000 (Stormwater Runoff)			
(two types)	Urban	14					30 - 8000 (Streetwash Runoff)			
Tulsa	Urban	15	(671 - 1,029)**		(230 - 477)**					
Oxhey, Eng.	Urban	16					2045 (Max)	194		
Lubbock, Texas	Urban	17	80 - 3,150	900	20 - 1,605	252				
Los Angeles	Urban	19					52 - 2488	530	20 - 1268	145
W. Lafayette,	Urban	20					1013 - 7330	224		
Indiana	Semi-Urban	20						955		
(3 locations)	Rural	20						246		

*Range of means reflecting the effect of type of crop and land management.

**Range of means reflecting the effect of seasonal climatic variation.

Table 2

BOD and COD Concentration of Stormwater

Location	Type of Area	Source	BOD (mg/l) Range	BOD (mg/l) Mean	COD (mg/l) Range	COD (mg/l) Mean
Cincinnati	Suburban	2, 3, 5	1 - 173	17	20 - 610	111
Coshocton, Ohio	Rural	21		(2.9 - 8.4)*		(40 - 80)*
Cincinnati	Suburban		1 - 220		20 - 810	
Lawrence, Kansas	Urban	8	4.6- 12.3	6.9	11 - 69	33
Detroit	Urban	7	96 - 234?			
Coshocton, Ohio	Rural	4	8.5- 23	7.0	30 - 159	79
Ann Arbor	Urban	9	62 (Max)	28.0		
Tulsa	Urban	10	8 - 18	11.8	42 - 138	85.5
Sacramento	Urban	11	24 - 283?		21 - 176?	
Washington, D.C.	Urban	12	6 - 625	126		
Oakland, Calif.	Urban	12	13 - 153	59		
Durham, N.C.	Urban	13	2.2- 232	31.3	40 - 660	224
Toronto	Urban	22	12 - 19			
Welland	Urban	22	19			
Stockholm	Urban	22	17 - 80		18 - 3100	183
Moscow	Urban	22	18 - 285			
Leningrad	Urban	22		36		
Pretoria, S . Africa (2 locations)	Urban	22		30 (Res., park area) 34 (Bus. and flat area)		
Seattle	Urban	22		10		
Minsk (Russia) (2 locations)	Urban	14	12.5- 145 (stormwater) 6.1- 223 (streetwash)			
Tulsa	Urban	15	6.0- 8.6**		32 - 65**	
Oxhey, Eng.	Urban	16	100 (Max)	7		
Lubbock, Texas	Urban	17	10 - 72	25		
W. Lafayette, Indiana (3 locations)	Urban	20		36		140
	Semi-Urban			10		72
	Rural			4		14

*Ranged of means reflecting the effect of type of crop and land management

**Range of means reflecting the effect of seasonal change

Seasonal Variations

Weibel, et al (5) investigated the possible fluctuation of pollution parameters in Cincinnati stormwater runoff with seasonal change. Table 3 shows that there is no pronounced change in the parameters with the possible exception of BOD.

Table 3

Seasonal Variations of Constituents in Stormwater Runoff, Cincinnati, Ohio (5)

	1962		1963		
Constituent	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep
S.S., mg/1	180	160	260	250	190
V.SS., mg/1	43	41	63	62	48
COD, mg/1	110	84	110	100	100
BOD, mg/1	30	28	12	19	15

Cleveland, et al (15) found that the pollutional parameters remain fairly constant throughout the year (bacterial considerations are covered in another section of this review of literature). Table 4 gives a summary of the means found for various pollutional parameters for different seasons in the Tulsa, Oklahoma area.

Table 4

Average of Parameter Concentration by Season from All Drainage Basins, Tulsa, Oklahoma (15)

Parameter	Fall	Winter	Spring	Summer
BOD, mg/l	6.7	6.0	8.1	8.6
COD, mg/l	32	52	65	44
Total Solids, mg/l	770	725	1029	671
Volatile Solids, mg/l	243	230	477	322

Effect of Land Use

There have been several reports that deal with stormwater runoff as it relates to the degree of urbanization. These reports deal with some attempt to correlate pollutional indicators with land use, population densities, social and economic differences within an area, percentage of impermeable surface in the area, etc.

Palmer (6) found that stormwater from a Detroit watershed, which was highly urbanized and densely populated, was "heavily polluted and would be but slightly less objectionable in the receiving waters than in the runoff from combined sewers."

Angino (8) analyzed the degree of urbanization of Lawrence Kansas and found that 35-40 percent of the surface area of the 460 acre drainage basin was impermeable. The non-surfaced areas were grassy. The area was largely residential and consisted of single family dwellings, university buildings, fraternities and sororities, apartment houses and dormitories. He stated that although urban areas only occupy 5 percent of the land in the United States they make up over 65 percent of the population. This fact indicates the potential hazard that stormwater represents.

The studies that dealt with the stormwater runoff from the watershed in suburban Cincinnati (2, 3, 4, 5) described the area as a residential and light commercial area. The buildings in the watershed include 45 single-family homes, 4 four-family apartments, 30 stores and restaurants, a firehouse, church, and other public buildings. The population density of this area is 9 persons per acre while the population density of all of Cincinnati is 10 persons per acre. The impermeable area (roofs, paved streets, and paved parking lots) is about 37 percent of the total drainage basin. The remainder consists of lawns, gardens, and parks. Some of the streets in the area have grassed or gravelled gutters which may be a significant source of solids when, during runoff, car wheels traverse them. It was determined that even though the area under investigation represents a relatively clean type of urban land use, it appears from the concentrations presented in Tables 1 and 2 that the urban stormwater runoff, without treatment, may not be acceptable to many receiving streams in the United States.

The AVCO Economic Systems Corporation (10, 15) performed a very thorough study of several Tulsa, Oklahoma urban watersheds. The total drainage basin was divided into 15 test sites. Each test site was classified as to land use. Table 5 gives a general description of the test areas. Table 6 gives the percentage of land devoted to various land use activities in each test area. Table 7 shows how the pollution parameters vary for different land uses. The residential areas and the light industry area yielded the highest BOD and COD values with the residential areas having the higher BOD and COD values of the two areas. The residential area with the highest BOD and COD values was upper middle class with a population density of 16.88 persons per acre. The highest solids concentration appeared in the light industrial area. Again, the residential areas significantly effect the quality of the stormwater runoff. Table 8 compares the pollution parameters for different land uses. From the table it can be seen that industry, open space, and streets, in that order, contribute heavily to total and suspended solids. Industrial, open space, and residential areas, in that order, contribute heavily to the BOD and COD concentrations found in stormwater runoff.

The largest portion of the pollutants from the test areas resulted from the erosion of drainage ditches caused by the scouring action of high volume runoff, generated on impervious areas and from the washing away of deposited

Table 5

General Description of Test Areas, Tulsa, Oklahoma (15)

Test Area No.	General Land Use Classification	Socioeconomic Class	Population Per Residential Acre
1	Industrial	Middle Class	12.07
2	Commercial	Upper Middle Class	13.09
3	Residential	Upper Middle Class	12.62
4	Mixed	Lower Middle Class	15.44
5	Residential	Upper Middle Class	16.88
6	Industrial	Lower Middle Class	10.00
7	Residential	Upper Middle Class	17.77
8	Residential	Lower Middle Class	22.02
9	Residential	Lower Class	29.13
10	Commercial Office and Residential	Lower Middle Class	26.82
11	Residential and Commercial	Lower Middle Class	21.25
12	Industrial	N.A.	N.A.
13	Residential	Lower Upper Class	3.13
14	Recreational	Upper Class	3.52
15	Residential	Lower Middle Class	15.96

Table 6

Percentage of Land Devote to Various Land Use Activities in Fifteen Base Areas of Tulsa, Oklahoma (15)

Test Area No.	Residential	Commercial	Industrial	Open Space	Streets
1	4.23	8.89	47.35	24.77	14.71
2	30.32	23.82	.36	25.27	20.22
3	56.54	5.09	0	19.46	19.09
4	24.94	27.71	18.34	6.18	22.81
5	52.86	11.44	.02	15.78	19.72
6	32.60	6.25	35.05	2.99	23.09
7	64.97	10.66	0	.51	23.85
8	51.66	10.90	4.74	4.27	28.44
9	46.86	10.93	0	4.69	37.48
10	16.02	17.96	0	15.53	50.48
11	44.99	4.17	5.03	4.05	41.68
12	0	48.36	1.41	50.23	0
13	75.47	2.83	0	2.36	19.81
14	27.00	0	0	65.40	7.60
15	70.25	1.35	0	6.76	21.62
Average	39.91	12.69	7.50	16.55	23.37

Table 7

Averages and Ranges for Selected Stormwater
Pollution Parameters from 15 Test Areas in Tulsa, Oklahoma (10, 15)
September 1968 to September 1969

Test Area No.	Class-ification	# of Events	BOD (mg/l)		COD (mg/l)		# of Storms	# of Samples	Average Total Solids	Solids Total S.S.	(mg/l) Total S.V.S.
			Avg.	Range	Avg.	Range					
1	Light Industry	14	13	3-23	110	54-215	14	36	2242	2052	190
2	Commercial	11	8	2-16	45	21-94	10	23	275	169	106
3	Res.	13	8	2-21	65	20-162	16	48	680	280	400
4	Mixed	13	14	4-29	103	14-232	15	46	616	340	276
5	Res.	11	18	3-38	138	37-261	13	50	271	136	135
6	Medium Ind.	10	12	6-18	90	39-133	10	15	346	195	151
7	Res.	14	8	2-17	48	12-69	18	60	413	84	328
8	Res.	9	15	3-25	115	50-405	8	13	382	240	141
9	Res.	11	10	4-15	117	40-263	11	16	417	260	157
10	Comm. (office) & Res.	11	11	4-27	107	36-240	11	34	431	300	132
11	Res. & Com.	11	14	4-23	116	80-167	11	26	575	401	174
12	Ind.	12	8	6-16	45	21-69	11	27	199	89	110
13	Res.	6	15	4-39	88	13-220	10	30	469	332	137
14	Rec. (Golf)	4	11	6-23	53	22-74	5	18	592	445	147

Table 7, cont.

15	Res.	6	12	1-24	42	18-62	8	22	273	183	89
Avg.		10.4	12		85		11.4	30.9	545	367	178

Table 8

Average Concentrations of Stormwater Pollution
Parameters for Different Land Uses
In Tulsa, Oklahoma (15)

Parameter	Residential	Commercial	Industrial	Open Space	Streets
BOD, mg/1	12.7	12.2	13.1	11.6	13.1
COD, mg/1	94	90	106	81	100
Total Solids, mg/1	512	598	1330	804	606
Suspended Solids, mg/1	299	397	1128	617	432

material on these impervious areas. It was found that the land surface characteristics which have the strongest parametric relationships with stormwater pollutant concentrations are the environmental conditions, the geomorphic characteristics which affect drainage, and the degree of the urban development. The last mentioned characteristic is evidenced by the amounts of streets, the type of streets, the amount of covered storm sewer, and the ratio of covered storm sewer to total length.(10)

The study results indicate that, within the residential sector, pollution parameter concentrations increase with increasing population densities. It was also noted that "land surface characteristics which influence the drainage of a watershed affect the amount of pollution produced per unit area to a larger degree than the recorded environmental deficiencies or the types of land activity".(10)

In another attempt to relate the degree of urbanization to stormwater runoff pollution, Bryan (13) selected several parameters for basin characterization of Durham, North Carolina watersheds. These parameters were land area, population density, length of the main stream channel, average slope of this channel, average slope of land areas, land use, environmental "quality" of the land use, and land surface characteristics. The last three parameters need some explanation.

The land use information was obtained by field inspection of individual blocks in each sub-basin. The criteria was strictly subjective and relative. The land use classifications used were: Residential (high, medium, and low quality), commercial and industrial, public and institutional, and unused. Streets and roads were considered as belonging to the land use associated with their position with exception of the expressway in the area which was considered as public. During field inspection of the basin, a judgement was made of environmental "quality". Criteria used in arriving at a decision as to whether the quality was good, fair or poor were: 1) general appearance of lands surfaces, 2) presence or absence of litter, 3) judgement of care in land surface maintenance, 4) presence or absence of lawns and other intended vegetation, and 5) such other factors as would subjectively influence the observer toward arriving at a conclusion as to the environmental "quality" of the area. The land surface characteristics were separated into four categories: paved streets, sidewalks and parking lots; unpaved streets; roof surfaces; and, lawns, undeveloped land and park areas.

The total basin characterization is given in Table 9. The main basin is about 60 percent residential, 20 percent commercial and industrial, and 20 percent public, institutional, and non-used with 33 percent of the basin being impermeable. The environmental "quality" of the basin is considered

Table 9

Summary of Basin Numerical Characterization, Durham, North Carolina (13)

Characteristic	Major Division		Major Basin
	N*	W**	M
Sub-basin area acres	693	376	1069
Population density per acre	10.5	8.2	9.7
Land use - percent of basin			
Residential - high quality	7.3	27.2	14.3
Residential - medium quality	10.3	26.9	16.2
Residential - low quality	31.1	24.8	29.0
Residential - TOTAL	48.7	78.9	59.5
Commercial and Industrial	27.9	1.7	18.6
Public/Institutional	12.0	11.5	11.8
Unused	11.5	7.9	10.1
Environmental quality percent of basin			
Good	51	51	51
Fair	17	26	20
Poor	32	23	29
Land surface characteristics - percent of basin			
Paved streets and parking lots	24	13.4	20.2
Roof tops	10.2	6.9	9.1
Unpaved streets	2.8	4.5	3.4
Undeveloped (lawns, park, etc)	63.0	75.2	67.3

*Basin "N" consists of 4 sub-basins

**Basin "W" consists of 3 sub-basins

generally good based on the criteria previously discussed. The characteristics of stormwater runoff at peak flow for major sub-basin "N" were: discharge, 14.3 CFS; total solids, 2370 mg/l; total volatile solids, 224 mg/l; and COD 236 mg/l. The characteristics of sub-basin "W" were: discharge, 11.4 CFS; total solids, 484 mg/l; total volatile solids, 87 mg/l; and COD, 57 mg/l. The characteristics of the entire basin were: discharge, 27.7 CFS; total solids, 1540 mg/l; total volatile solids, 178 mg/l; and COD, 140 mg/l. Those parameters that appear to have the greatest affect on the runoff quality are environmental "quality", land surface characteristics, and population density.

In a study performed in Chicago by the American Public Works Association (23), pollution contributed by such factors as street cleaning methods, catch basins at storm sewer inlets, air pollution, and the use of certain chemicals in urban activities were investigated and evaluated. Lab tests indicated that actual pollution of storm runoff by street litter and dust, as measured by the BOD of the soluble dust and dirt fraction in "mg per gram", is about one percent of that of raw sewage and five percent of treated sewage effluent. However, the shock loading from possible flushing action could be as high as 160 percent of the values from raw sewage and 800 percent of those of treated sewage effluent. Results of the study show that catch basins, which hold a large fraction of solids during periods of low flow, may be one of the largest single sources of pollution from stormwater flows due to the possibility of anaerobiosis occurring in the settled solids.

Pravoshinsky (14) indicated that the pollution of surface runoff from Minsk streets depended on a number of factors: the intensity of traffic (auto and pedestrian); type of cover of catchment; duration and intensity of rain; amount of dust deposition; antecedent dry period; quality and technology of town cleaning; and a combination of these and other factors.

Schulz (20) compared stormwater runoff quality from an urban, semi-urban, and rural watershed located in the West Lafayette, Indiana area. He found that the runoff from the urban watershed has higher BOD and COD concentrations than those found in the runoff from the other watersheds. The suspended solids concentration in the runoff from the semi-urban watershed is generally much higher than in the runoff from the urban and rural watersheds. Table 10 gives a summary of the pollutional characteristic in stormwater runoff from the three areas in West Lafayette.

First Flush, Low-Intensity Rainfall, and Antecedent Dry Period

In the studies performed on the watersheds in the Cincinnati suburb by the Robert A. Taft Sanitary Engineering Center (2, 3, 4, 5), the topic of first flushing was discussed. It was found that suspended solids varied with discharge. In

Table 10

Characteristic of Pollution in Stormwater Runoff from an Urban, Semi-Urban, & Rural Watersheds in the West Lafayette, Indiana Area (20)

Parameter	Urban			Semi-Urban			Rural		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
BOD, mg/l	2.5	145.5	36.4	4.0	19.8	10.3	1.8	6.6	4.0
COD, mg/l	21.8	369.4	139.7	34.8	175.7	93.2	18.5	52.3	32.2
SS, mg/l	20	824	224.3	86	2720	955.3	17	646	244.3
V.SS., mg/l	0	168	56.1	15	190	96.0	4	102	37.1

one case a "first flush" of solids did not occur until rainfall and runoff rates developed 2 1/2 hours after the storm started; and, still further, that after an additional 2 hours of gentle rain a substantial rise in rainfall and runoff was accompanied by a second flush of suspended solids. In other rainfalls at this site an early flush of suspended solids developed, followed by other flushes at runoff peaks. The effect of "first flush" in runoff quality is evident in the data presented in Table 11. The data is derived from storms of short duration and high intensity as well as from longer storms.

Table 11

Mean Concentration of Constituents in
Urban Land Runoff Versus Time,
Cincinnati, Ohio (5)

	Time After Start of Runoff (Min.)				
Parameter	0-15	15-30	30-60	60-120	120 and over
SS, mg/l	390	280	190	200	160
VSS, mg/l	98	69	47	58	38
COD, mg/l	170	130	110	97	72
BOD, mg/l	28	26	23	20	12

Palmer (6) studied the effect of low-intensity rainfall on stormwater runoff quality and found that low-intensity storms, which are more frequent, result in the majority of heavily polluted runoff. In regards to first flush he stated that, "In some cases the quality of the material became worse as the storm progressed and in others it became better, and in still others no pattern was apparent."

Burm, et al (9) examined the stormwater runoff quality from Ann Arbor, Michigan watersheds and found that suspended solids were higher at peak flows than at first flush. However, the first flush of suspended solids was apparent. Table 12 presents the values of several quality parameters versus time obtained from the Ann Arbor studies.

Table 12

Average Annual Discharge Concentration
at Various Time Increments,
Ann Arbor, Michigan (9)

	Minutes After Beginning of Discharge*									
Analyses	0-4		4-9		9-19		19-34		>34	
BOD, mg/l	(9)	47	(7)	20	(9)	15	(10)	13	(12)	16
SS, mg/l	(15)	2390	(12)	1130	(18)	1810	(12)	2820	(14)	2270
VSS, mg/l	(13)	301	(12)	207	(18)	177	(12)	237	(14)	178

*Figures in parentheses represent the number of results averaged together for the particular analysis and time period.

Bryan (13) indicated the existence of a "first flush" phenomena in stormwater runoff from Durham, North Carolina watersheds. He found that a substantial flow was required in order to generate a large quantity of solids. He defined two portions of the solids concentration curve based on their relative position on the curve to the peak. The "first flush rising limb" is that portion of the solids concentration curve that is marked by the increasing flow and increasing solids concentration prior to peak concentration. The "first flush falling limb" is that portion of the solids concentration curve that is marked by a peaking inflow and decreasing solids concentration after peak concentration. Table 13 summarizes his findings for one particular storm over a period of several days.

Table 13

Summary of Analytical Results for Samples Examined for Pesticides, Durham, North Carolina (13)

Sample Identification	A	B	C	D	E
Date of Sample	6-13	6-13	6-15	6-15	6-16
Time of Sample	1 P.M.	3 P.M.	10 A.M.	8 P.M.	1 P.M.
Discharge Rate (CFS)	1.70	27.7	40.6	114	1.1
T.S. (mg/l)	486	1540	9900	3740	318
T.V.S. (mg/l)	94	178	737	324	64
COD (mg/l)	80	140	377	180	79

A. Base flow before storm

B. First minor peak

C. First flush rising limb

D. First flush falling limb

E. Base flow after storm

Wilkinson (16) analyzed stormwater runoff from an Oxhey, England housing estate and noted the possible existence of a "first flush" affect. He found that in most storms there was a "first flush" of water which was more polluting than the rest of the storm, but in many storms the runoff water remained turbid for a considerable time and the water discharged throughout the storm was stronger than the "first flush". It was apparent that the catchment area was not rapidly washed clean by the first flush of water. Table 14 gives a summary of his findings.

Wilkinson also mentioned the effect of antecedent dry-weather periods on stormwater runoff quality and found that BOD increases with increasing antecedent dry-weather periods of up to 8-10 days. Pravoshinsky (14) presented the quantity of pollutants carried by stormwater runoff in terms of the amount and intensity of precipitation and the duration of the antecedent dry-weather period. It was found that the longer the dry period the higher the pollutant for a given amount of precipitation, up to a certain point and given amount, the higher the intensity of rainfall the higher the pollutant value for any given antecedent dry period.

Weidner, et al (21) tried to correlate soil losses from the Coshocton, Ohio rural watersheds to total solids found in stormwater runoff. It was found that the type of land management practice affected the soil loss. More soil was lost using prevailing practice than was lost using improved

Table 14

Weight of Polluting Matter and Average Composition of Surface Runoff Waters from the Oxhey Estate Between April 1, 1953 and March 31, 1954, in 79 out of 131 Known Storms, Oxhey, England (16)

Quantity Measured	Total Discharge	First 30 Min. of each storm	30 Min.- 360 Min.	After 360 Min.	First 55,000 Gal	After 55,000 Gal
Duration of Flow (Min.)	9485	2320	4870	2295	2162	7323
Average Rate of Run-off (GPM)	2.1	2.4	2.0	1.8	1.9	2.1
BOD, (mg/1)	7	13	6	3	14	6
S.S., (mg/1)	194	341	150	100	303	168

practice. It was also found that soil loss was affected by the type of crop and that the soil loss decreased in order from corn to wheat to meadow. A regression line for total solids and silt losses was determined and a correlation coefficient of 0.99 was found, indicating a definite correlation.

Weibel, et al (5) attempted to correlate rainfall to both runoff suspended solids and runoff BOD. He also attempted to correlate flow ranges to mean suspended solids concentrations. Figure 1 shows that as the amount of rainfall increased so did runoff suspended solids. Figure 2 indicates an increase in BOD with an increase in the amount of rainfall. Figure 3 showns that the mean suspended solids concentration increased as the flow increased.

Weibel, et al (5) compared stormwater runoff loads and sanitary sewage loads (lb/yr/acre) for a watershed in suburban Cincinnati. The results of this comparison are shown in Table 15.

Table 15

Comparison of Stormwater Runoff Loads and Sanitary Sewage Loads (lb/yr/acre), Cincinnati, Ohio (5)

Parameter	Stormwater Runoff*	Raw Sanitary Sewage**	$\frac{\text{Storm}}{\text{Sanitary}}$, %
S.S., mg/l	730	540	140
V.S.S., mg/l	160	360	44
COD, mg/l	240	960	25
BOD, mg/l	33	540	6

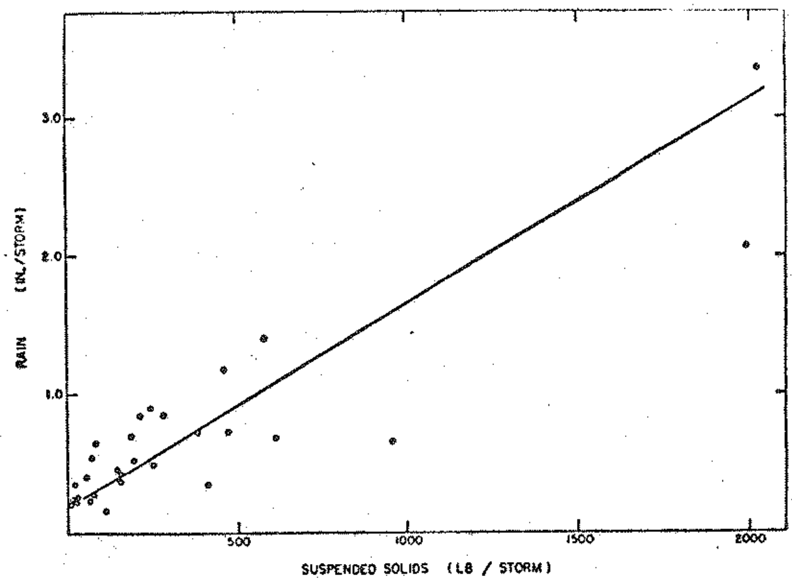

FIGURE 1—Rainfall vs. runoff suspended solids. (In. × 2.54 = cm; lb × 0.454 = kg).

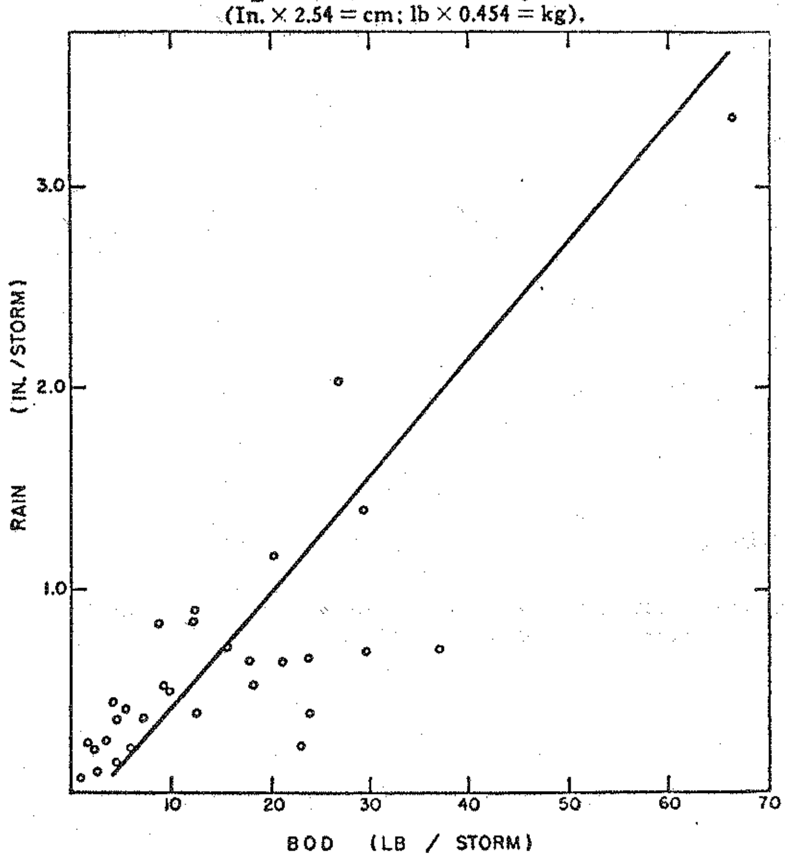

FIGURE 2—Rainfall vs. runoff BOD. (In. × 2.54 = cm; lb × 0.454 = kg).

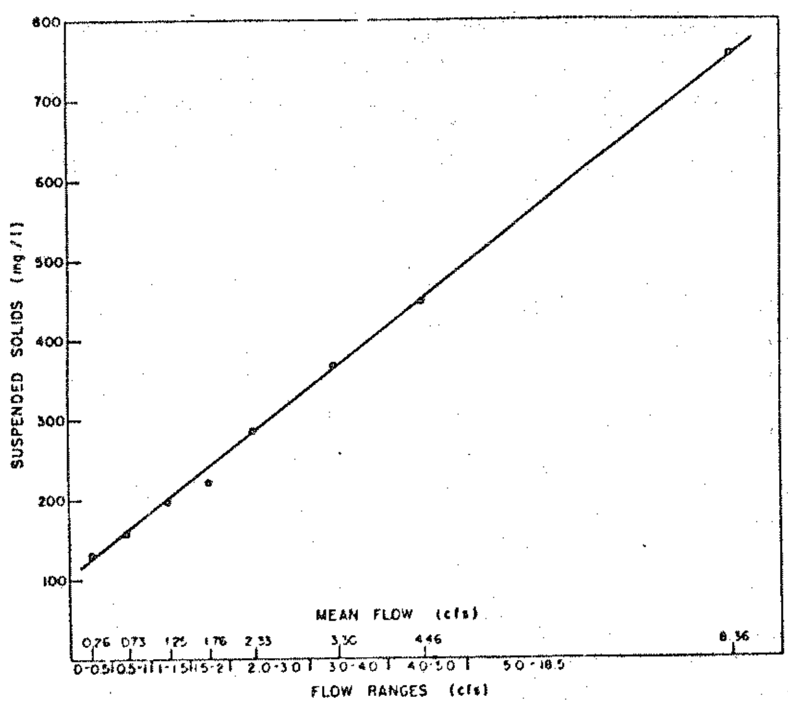

FIGURE 3—Mean suspended solids concentrations found within different ranges of flow. (Cfs × 1.7 = cu m/min).

*Stormwater runoff-based on essentially complete measurement of rainfall and consequent runoff water quality at the study site during Sept. - Nov. 1962 and Mar. - Sept. 1963, projected to average annual rainfall at Cincinnati.

**Sanitary sewage-based on population density of 9 persons per acre and flow of 100 gallon per capita per day assumed raw sewage strengths: SS-200 mg/l; VSS-130 mg/l; COD-350 mg/l; BOD-200 mg/l.

Brownlee, et al (17) compared runoff quality from Lubbock, Texas watersheds with raw sewage classification as proposed by Babbitt and Baumann. The comparison is shown in Table 16. The table shows that stormwater runoff in the Lubbock area is stronger than raw sewage in the suspended solids category. It also shows that runoff quality is poorer than weak sanitary sewage in all categories except BOD.

Table 16

Comparisons of Runoff Quality, Lubbock, Texas (17)

Parameter	Raw Sewage			Runoff from Study Area
	Strong	Medium	Weak	
Total Solids, mg/l	1000	500	200	900
Total Volatile Solids, mg/l	700	350	120	252
Suspended Solids, mg/l	500	300	100	530
Suspended Volative Solids, mg/l	400	250	70	145
BOD, mg/l	300	200	100	25

Schulz (20) compared pollution parameters in stormwater runoff from three watersheds in West Lafayette, Indiana with domestic sewage and secondary sewage treatment plant effluent. He found that solids concentration from three watersheds exceeded that found in domestic sanitary sewage and the concentration of pollutants in the runoff from the urban watershed was greater than that of secondary treatment plant effluent with 90 percent removal efficiency. Table 17 shows the results of the comparison.

The reports all indicate that stormwater runoff is a significant source of pollution in streams in the United States. They point out that solids concentration in stormwater runoff is greater than that found in domestic sewage and that the overall quality of stormwater runoff is generally much worse than secondary treatment plant effluent.

Bacteriological Characteristics of Stormwater Runoff

General

Total and fecal coliform analyses have been used traditionally as indicators of possible pathogen contamination. Geldreich (24) considered the significance of fecal coliforms and concluded that the fecal coliform test has been demonstrated to be the most accurate measurement of the occurrence of warm blooded feces in polluted water. It is for this reason that the presence of total and fecal coliforms in stormwater runoff is usually determined.

Table 17

Comparison of the Pollution Parameters in Stormwater Runoff with Domestic Sewage and Secondary Sewage Treatment Plant Effluent in the West Lafayette, Indiana Area (20)

Parameter	Mean Values for Watersheds			Sanitary Sewage	Treatment Plant Effluent (90% Removal Efficiency)
	Urban	Semi-Urban	Rural		
BOD, mg/1	36.4	10.3	4.0	200	20
COD, mg/1	139.7	93.2	32.2	350	35
TS, mg/1	479.6	1136.9	619.3	400	40
TVS, mg/1	159.2	179.7	160.7	230	23
SS, mg/1	224.3	955.3	244.3	200	20
VSS, mg/1	56.1	96.0	37.1	130	13

Geldreich, et al (24, 25) considered the correlation between coliform bacteria derived from non-polluted soil and the fecal coliform test in order to determine the number of bacteria that soil may contribute. He found (24) that unpolluted soil showed less than 2 fecal coliform per gram but soil from land that was flooded with sewage or riverbanks along heavily polluted streams had fecal coliform densities from 3,000 up to 49,000 organisms per gram. He found (25) that the major contamination of storm runoff occurred with stormwater runoff from polluted land. He states that, "Soil in areas remote from man and his culture receives insignificant levels of occasional contamination from wild animals and, therefore, generally does not contain any fecal coliforms. In contrast, soil in areas populated by man, either on farms or in cities, receives varying levels of warm-blooded animal pollution from humans, pets, farm animals, and rodents. As a result, soil contributes fluctuating densities of fecal contamination to drainage water, the amount being related to the intensity and frequency of soil pollution."

Geldreich also considered the bacterial contribution that rainfall and pets and rodents make to stormwater runoff. He stated (25) that "infrequently rain or snow falling to the earth is contaminated with traces of matter and occasional bacteria acquired via air-borne particulates." He found that the average total coliforms was less than 10 organisms per 100 ml and the average fecal coliform was less than 0.7

organism per 100 ml. The maximum values found in rainwater for total and fecal coliforms were 92 organisms per 100 ml and 1 organism per 100 ml, respectively. He also found (24) that fecal contamination in seperate stormwater systems is ultimately related to the fecal discharges of cats, dogs, and rodents in the urban areas. Agricultural land drainage contains the fecal contamination from farm animals and wild life. He showed that cat and dog feces contain 7,900,000 and 23,000,000 organisms per gram, respectively, and that rat, chipmunk, and rabbit feces contain 330,000 organisms per gram, 150,000 organisms per gram, and 20 organisms per gram, respectively.

Weibel, et al (2, 4, 5) investigated the bacteriological quality of stormwater runoff from a 27-acre residential, light-commercial suburb of Cincinnati, Ohio. The total coliform counts exceeded 2,900 organisms per 100 ml, 58,000 organisms per 100 ml, 460,000 organisms per 100 ml in 90 percent, 50 percent, and 10 percent of the samples, respectively. The fecal coliform counts exceeded 500 organisms per 100 ml, 10,900 organisms per 100 ml, and 76,000 organisms per 100 ml in 90, 50, and 10 percent of the samples respectively.

In a more recent study (1964-66) of the same Cincinnati suburban watershed performed by Evans, et al (3), the following ranges of coliform densities were found: Total coliforms, 23,900 - 45,000,000 organisms per 100 ml; and, fecal coliforms, 1,050 - 1,210,000 organisms per 100 ml.

Palmer (6) studied stormwater runoff from a watershed in Detroit resulting from four separate low-intensity storms in 1960. The storms occurred on August 13 and 26 and September 12 and 19. The ranges of total coliforms (expressed in organisms per 100 ml) for the storms were: August 13, 1960: 150,000 - 230,000; August 26, 1960: 2,300 - 430,000; September 12, 1960: 2,300 - 150,000; and September 19, 1960: 9,100 - 430,000. The means for the latter two storms were 25,600 and 173,025, respectively. Palmer (7) had previously determined a range for total coliforms of 25,000 and 930,000 organisms per 100 ml for the same watersheds.

Burm and Vaughan (26) examined total and fecal coliform densities in stormwater runoff from an Ann Arbor watershed. Table 18 gives the results obtained from twenty-two overflows successfully monitored in five months. The maximum total and fecal counts were 49,000,000 and 4,300,000 organisms per 100 ml, respectively.

Benzie and Courchaine (27) determined median total and fecal coliform densities for the 1964 study of the same watershed in Ann Arbor and found them to be 1,200,000 and 82,000 organisms per 100 ml, respectively.

Geldreich, et al (25) compared total and fecal coliform densities of stormwater from different areas in Cincinnati and compared the effect of climatic seasonal changes of the densities. The ranges of the median values for total and fecal coliform densities were 260 - 290,000 and 20 - 47,000 organisms per 100 ml, respectively.

Table 18

Statistical Summary of Ann Arbor Overflows During 1964 (26)

Months	Overflows Successfully Monitored at Ann Arbor	Coliform Analysis	Organisms per 100 ml: Range of Geometric Means	Organisms per 100 ml: Median Densities of Geometric Mean
April	3	Total	12,000 - 350,000	340,000
		Fecal	7,400 - 17,000	10,000
May	2	Total	139,000 - 880,000	510,000
		Fecal	29,000 - 73,000	51,000
June	5	Total	190,000 - 10,000,000	4,000,000
		Fecal	24,000 - 130,000	78,000
July	7	Total	390,000 - 15,000,000	4,000,000
		Fecal	60,000 - 560,000	120,000
August	7	Total	220,000 -34,000,000	1,700,00
		Fecal	160,000 - 750,000	350,000

In the study performed by the Avco Economic Systems Corporation (10) in Tulsa, the total and fecal coliform densities ranged from 5,000 to 400,000 and from 10 to 18,000 organisms per 100 ml, respectively. The means were 87,000 and 470 organisms per 100 ml, respectively. In the study performed by the Envirogenics Company (11) in Sacramento California, fecal coliforms ranged from 2,400 to 1,000,000 organisms per 100 ml.

The Public Health Service (12) found that in Oakland, California total coliform densities of stormwater runoff varied from 2,300 to 2,400,000 organisms per 100 ml with a mean value of 293,000 organism per 100 ml. Bryan (13) examined the bacteriological quality of stormwater runoff in a Durham, North Carolina watershed and reported that for 37 samples the densities of fecal coliform ranged from 3,000 to 1,900,000 organisms per 100 ml with a mean of 248,000 organisms per 100 ml. The Los Angeles Flood Control District's Water Conservation Division (18, 19) determined the ranges of total coliform counts was 0 to 1,100,000 organisms per 100 ml. For the period 1967-68, the range was 800 to 3,320,000 organisms per 100 ml.

Weidner, et al (21) examined the stormwater runoff from five rural watersheds near Coshocton, Ohio, for total and fecal coliform. He found that the median densities for the five watersheds ranged from 2500 to 8100 organisms per 100 ml for total coliforms and from less than 2 to 1200 organisms per 100 ml for fecal coliforms.

Other studies have been performed in Toronto, Welland (Canada), Stockholm, Pretoria (South Africa) and Seattle. The results of these studies are presented in Table 19 along with a summary of the studies previously discussed.

Seasonal Variations

Evans, et al (3) gave bacterial densities in urban stormwater runoff from a watershed in a Cincinnati watershed. Table 20 illustrates the effect of seasonal climatic changes on coliform counts. As can be seen from the table, coliform density increases in warmer climates and reaches a maximum value in late summer or early fall with a minimum occurring in the winter.

Burm and Vaughan (26) discussed the effect of seasonal climatic changes on coliform densities of stormwater runoff from an Ann Arbor watershed. Table 21 gives the range of geometric means and median densities of geometric mean for total and fecal coliform for the months of April through August. A definite rising trend exists during the warmer summer months for both fecal and total coliforms.

Geldreich, et al (25) also discussed seasonal variations for bacterial discharges in stormwater and rainwater from the Cincinnati suburban area and a rural area near Coshocton, Ohio. Table 22 gives the median values of geometric means for four types of areas for the four seasons.

Table 19

Bacteriological Characteristics of Stormwater

(Counts/100 ml)

Location	Type of Area	Source	Total Coliform Range	Total Coliform Mean	Fecal Coliform Range	Fecal Coliform Mean
Cincinnati	Suburban	2		58,000		10,900
Detroit	Urban	6	150,000 - 230,000			
(4 storms)			2,300 - 43,000			
			2,300 - 150,000	25,600		
			9,100 - 430,000	173,025		
Coshocton (Ohio)	Rural	21	(2,500 - 8,100)*		(<2 - 1,200)*	
Cincinnati	Suburban	3	23,900 - 45,000,000		1,050 - 1,210,000	
Detroit	Urban	7	25,000 - 930,000			
Ann Arbor	Urban	26,27	120,000 - 350,000	340,000	7,400 - 17,000	10,000
(5 storms)			139,000 - 880,000	510,000	29,000 - 73,000	51,000
			190,000 - 10,000,000	4,000,000	24,000 - 130,000	78,000
			390,000 - 15,000,000	4,000,000	60,000 - 560,000	120,000
			220,000 - 34,000,000	1,700,000	160,000 - 750,000	350,000
						13,000
Cincinnati	Urban	25				6,400
	Suburban St.					1,900
	City Park					2,700
	Rural					470
Tulsa	Urban	10	5,000 - 400,000	87,000	10 - 18,000	
Sacramento	Urban	11			24,000 -10,000,000	
Oakland	Urban	12	2,300 - 2,400,000	293,000		
Durham, N.C.	Urban	13			3,000 - 1,900,000	248,000
Toronto	Urban	22	4,300 - 1,800,000			
Welland	Urban	22		16,800		
Stockholm	Urban	22	40 - 200,000			
Seattle	Urban	22		16,000		
Tulsa	Urban	15	143,000 - 3,845,000**			
Los Angeles	Urban	18,19	800 - 3,320,000			

*Range of means found in a study of the effect of crop and land practices of runoff quality

**Range of means found for the four seasons of the year

Table 20

Bacterial Densities of Urban Stormwater Runoff, Cincinnati, Ohio (3)

Rainfall-Runoff Event	Indicator Density-Total Coliform	Organism per 100 ml Fecal Coliform
Mar. 23, 1966*	152,000	3,200
Jul. 7, 1964+	920,000	27,000
Aug. 5, 1965+	2,280,000	31,000
Aug. 19, 1965+	2,670,000	1,210,000
Sep. 15, 1965*	45,000,000	430,000
Sep. 22, 1965*	28,000,000	260,000
Nov. 24, 1964+	270,000	2,650
Feb. 6, 1964+	250,000	2,400
Feb. 10, 1966*	23,900	1,050

*Grab sample

+Flow-proportional sample

Table 21

Statistical Summary of All Ann Arbor Overflows (26)

Month	Overflows Successfully Monitored at Ann Arbor	Coliform Analysis	Range of Geometric Means	Median Densities of Geometric Means
April	3	Total	12,000 - 350,000	340,000
		Fecal	7,400 17,000	10,000
May	2	Total	139,000 - 880,000	510,000
		Fecal	29,000 - 73,000	51,000
June	5	Total	190,000 - 10,000,000	4,000,000
		Fecal	24,000 - 130,000	28,000
July	5	Total	390,000 - 15,000,000	4,000,000
		Fecal	60,000 - 560,000	120,000
August	7	Total	220,000 - 34,000,000	1,700,000
		Fecal	760,000 - 750,000	350,000

Table 22

Seasonal Variations (Median Values) for Bacterial Discharges in Stormwater and Rainwater from Suburban Areas (Cincinnati, Ohio) and in Agricultural Land Areas (Coshocton, Ohio) (25)

Source	Date	Total Samples	Season	Total Coliform	Fecal Coliform (Organisms/100 ml)
Wooded Hillside	Feb. 62 to Dec. 64	278	Spring	2,400	190
			Summer	79,000	1,900
			Autumn	180,000	430
			Winter	260	20
Street Gutters	Jan. 62 to Jan. 64	177	Spring	1,400	230
			Summer	90,000	6,400
			Autumn	290,000	47,000
			Winter	1,600	50
Business Dist.	Apr. 62 to Jul. 66	294	Spring	22,000	2,500
			Summer	172,000	13,000
			Autumn	190,000	40,000
			Winter	46,000	4,300
Rural	Jan. 63 to Aug. 64	94	Spring	4,400	55
			Summer	29,000	2,700
			Autumn	18,000	210
			Winter	58,000	9,000
Rainwater	Jun. 65 to Feb. 67	49	Spring	<1.0	<0.3
			Summer	<1.0	<0.7
			Autumn	<0.4	<0.4
			Winter	<0.8	<0.5

The table also gives values for rainwater prior to runoff. He found that "total coliform peak densities for urban locations (wooded hillsides, street gutters, and suburban business districts) occurred in autumn. This was also noted for fecal coliform --- densities in urban street gutters and business district stormwater runoff." Fecal coliforms, however,..."reached an earlier peak (summer period) for stormwater runoff collected from the wooded hillside." Rural stormwater runoff demonstrated "the possible existence of summer and winter peaks in bacterial indicator densities... These peaks may be related, in part, to more surface runoff during the summer growing season and the winter period of frozen ground conditions. In the spring and the autumn, however, land cultivation results in greater downward migration of water, with its associated bacteria, into the soil and groundwater table." The highest total fecal coliform densities occurred in autumn in stormwater from street gutters with median values of 290,000 and 47,000 organisms per 100 ml, respectively.

Cleveland et al (15) examined total coliform densities in stormwater runoff from Tulsa, Oklahoma watersheds. Maximum densities occurred in summer with a mean of 3,845,000 organisms per 100 ml, followed by spring with a mean of 704,000 organisms per 100 ml, fall with a mean of 403,000 organisms per 100 ml, and finally winter with a mean of 143,000 organisms per 100 ml.

Effect of Land Use

Table 22 points out another bacteriological aspect of stormwater runoff.(25) It can be seen that the type of land use affects the densities of coliforms found. As stated previously, the maximum total and fecal coliform densities were found in urban street gutters. The maximum coliform densities decreased from the business district to the wooded hillside to the rural area.

The AVCO Economic Systems Corporation (10) investigated the geometric means for bacterial density in urban stormwater from 15 test areas in Tulsa, Oklahoma. The test areas were classified by land use. Table 23 gives the results of the investigation. It can be seen that maximum total coliform densities occurred in residential districts and minimum densities in recreational areas. Maximum fecal coliform density appeared in the medium industrial area and the minimum fecal coliform density occurred in open land. Commercial areas appear to have intermediate values of total and fecal coliforms.

Weidner, et al (21) showed that land management practices effected coliform densities found in stormwater runoff from five rural watersheds near Coshocton, Ohio. The data in Table 24 reflect the differences in runoff quality due to two types of land management of the watersheds. One type of management, prevailing practice, consists of straight-row tillage across the slope, low level of fertilizing, liming to pH 5.4, and

Table 23

Geometric Means* for Bacterial Density (Thousands/100 ml)
In Urban Stormwater from 15 Test Areas in Tulsa, Oklahoma (17)
Sept. 1968 to Sept. 1969

Test Area No.	Classification	Total Coliform # of Events	Total Coliform Min.	Total Coliform Geom. Mean	Total Coliform Max	Fecal Coliform # of Events	Fecal Coliform Min.	Fecal Coliform Geom. Mean	Fecal Coliform Max
1	Light Industrial	14	0.0	71	2,000	11	0.0	0.94	70
2	Commercial	11	0.7	43	800	8		1.90	170
	Retail								
3	Residential	13	0.0	100	20,000	10		3.30	175
4	Med. Ind.-Res.	13	0.0	25	500,000	8		0.77	30
5	Res.	11	0.0	150	21,500	12		1.50	185
6	Med.	10	4.0	140	5,500	9		18.00	470
	Industry								
7	Res.	14	0.0	32	3,500	13		0.12	80
8	Res.	9	0.0	240	3,300	8		0.45	420
9	Res.	11	26.0	400	7,500	10		0.29	265
10	Office Commercial	11	2.0	130	3,800	11		0.30	45
11	Res.-Com. (Mix)	11	14.0	370	5,800	10		0.62	290
12	Open Land Runways	12	0.0	56	2,500	11		0.01	20
13	Res.	6	0.0	28	1,700	9		0.18	110
14	Rec. (Golf)	4	0.0	5	1,425	5		0.37	95
15	Res.	6	20.0	220	1,450	8		0.35	135

*Geometric means were calculated using the arithmetic means of each event sampled.

Table 24

Bacterial Counts in Stormwater Runoff Samples from a Rural Area Near Coshocton, Ohio (21)

Kind of Organism	Watershed No.	Counts Exceeded in Designated Percent of Samples (Storm Composites) (Counts per 100 ml) 90%	50%	10%
Coliform**	113 Imp.	220	3000	36,000
	118 Prev.	80	2500	42,000
	185 Imp.	1800	3000	70,000
	195 Prev.	100	4400	110,000
	196 M. Prev.	1300	8100	180,000
Fecal Coliform**	113 Imp.	<2	8	80
	118 Prev.	<2	<2	80
	185 Imp.	<2	20	1,100
	195 Prev.	<2	18	4,600
	196 M. Prev.	22	1200	56,000

*Sample taken during 1964

**Coliform and Fecal Coliform organisms were determined by MF techniques using M-ENDO and M-FC media, respectively using alsike-red clover-timothy mixture as a meadow crop. The second land management scheme, improved practice, consists of contour tillage, high level of fertilizing, liming to pH 6.8 and using a clover-alfalfa-timothy mixture for clover. The watersheds were either in corn (watershed numbers 113 and 118), wheat (watersheds numbers 185 and 192), or mixed cover (watershed number 196). The effect of crop and land management practice on total and fecal coliform densities can be seen in Table 24.

Sampling Methods and Equipment

Several different and imaginative methods have been used to obtain stormwater runoff samples and flow measurements. The sampling techniques used by the Robert A. Taft Sanitary Engineering Center in their studies of stormwater runoff at Cincinnati (2, 3, 4, 5, 25) gives some indication of this. In these studies, flows from a storm sewer were determined from a rectangular weir and recorder located in a ditch immediately below the pipe outlet. Samples were collected by means of a suction hose and a small battery-operated centrifugal pump located at a manhole 50-feet upstream of the storm sewer outfall. The pump discharged to a rotating distributor and 36-four liter carboys. A float device in the sewer started the pump when the flow started. The distributing arm was powered by a spring motor, rotated constantly over vertical tubes which were connected by hoses to the individual bottles. The arm took ten minutes to travel from the center of one hose to the next. The bacterialogical samples were collected in special containers. Samples of rainwater were also collected from a pair of large shallow trays which also allowed measurement of dust deposition over the antecedent dry period. Rainfall measurement was accomplished with a rainfall gage.

At the Coshocton station (4, 21) in Ohio, the Robert A. Taft center used a Parshall flume for flow measurement, and an arrangement for refrigerating the samples. The inlet device to the sampler was located in the flume and was assembled on a float device so that regardless of the flow in the flume the sample would be collected at mid-depth. Samples were stored in a refrigerator until the physical, chemical, and bacteriological analyses were made.

Another imaginative sampling device was constructed by the AVCO Economic Systems Corporation for use in the Tulsa, Oklahoma study (10, 15). The assembled device consisted of a peristaltic tube pump, inclined sequential sample container, voltage inverter, 12-volt battery, sampling probe, pressure diaphragm box, and a pressure recorder. An inclined sequential sample container and overflow jug are connected to the peristaltic pump with "tygon" tubing and a polyethylene quick disconnect.

The switch-float mechanism consisted of a polyethylene foam float connect to a length of aluminum conduit which is hinged at the top of the storm drainage structure. The aluminum conduit contained polyethylene tubing which is connected to the inlet side of the peristaltic pump. Attached to the aluminum conduit arm was a small micro-switch which was activated by a small metal arm extending down from the hinge.

The inclined sequential sample containers allowed the collection of samples for both bacteriological and physical, chemical analyses. As water was lifted by the peristaltic pump and entered the inlet side of the container, the sampler composited an amount of water into a 60-ml bottle. The water then travelled up the inclined tube to a 2-liter bottle until it was full. This sequence was repeated until all bottles were full. The 60-ml bottle was the bacteriological sample and the 2-liter bottle was for chemical and physical analyses.

In the Ann Arbor study (9, 26, 27), the samples were taken at about 5-minute intervals during the year due to the rapidly rising and falling hydrograph characteristics of the storm sewer. The sampling device consisted of a submersible pump set to be activated when the level of flow in the sewer rose 18 inches above the normal dry-weather flow. The pumps, on activation, lifted the liquid out of the sewer to an automatic sampler which consisted of a rotating turntable with 16 quart bottles and a hose which delivers the sample to the bottle. The sampler had a 90-second flushing period prior to sampling.

DESCRIPTION OF THE TEST WATERSHEDS AND SAMPLING STATIONS

Introduction

The watersheds and gaging-sampling stations were selected and defined by members of the Purdue University Hydraulics Department in a study entitled "The Effect of Urbanization on Runoff in Small Watersheds" and are now being used in conjunction with an interdisciplinary study of Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities. The interdisciplinary study includes the investigation of pollution parameters found in stormwater runoff from those watersheds defined in the previously mentioned report.

The location of the gaging-sampling stations for the two watersheds used for this study is shown in Figure 4. The Civil Engineering Building is shown on the map to show the distance of the gaging and sampling stations from the laboratory in which all analyses were made.

Urban Watershed

The urban watershed has an area of 29 acres, and includes a fully developed residential area northeast of Northwestern Avenue, West Lafayette. The residential area consists of 72 single-family dwellings. The population of the area, based

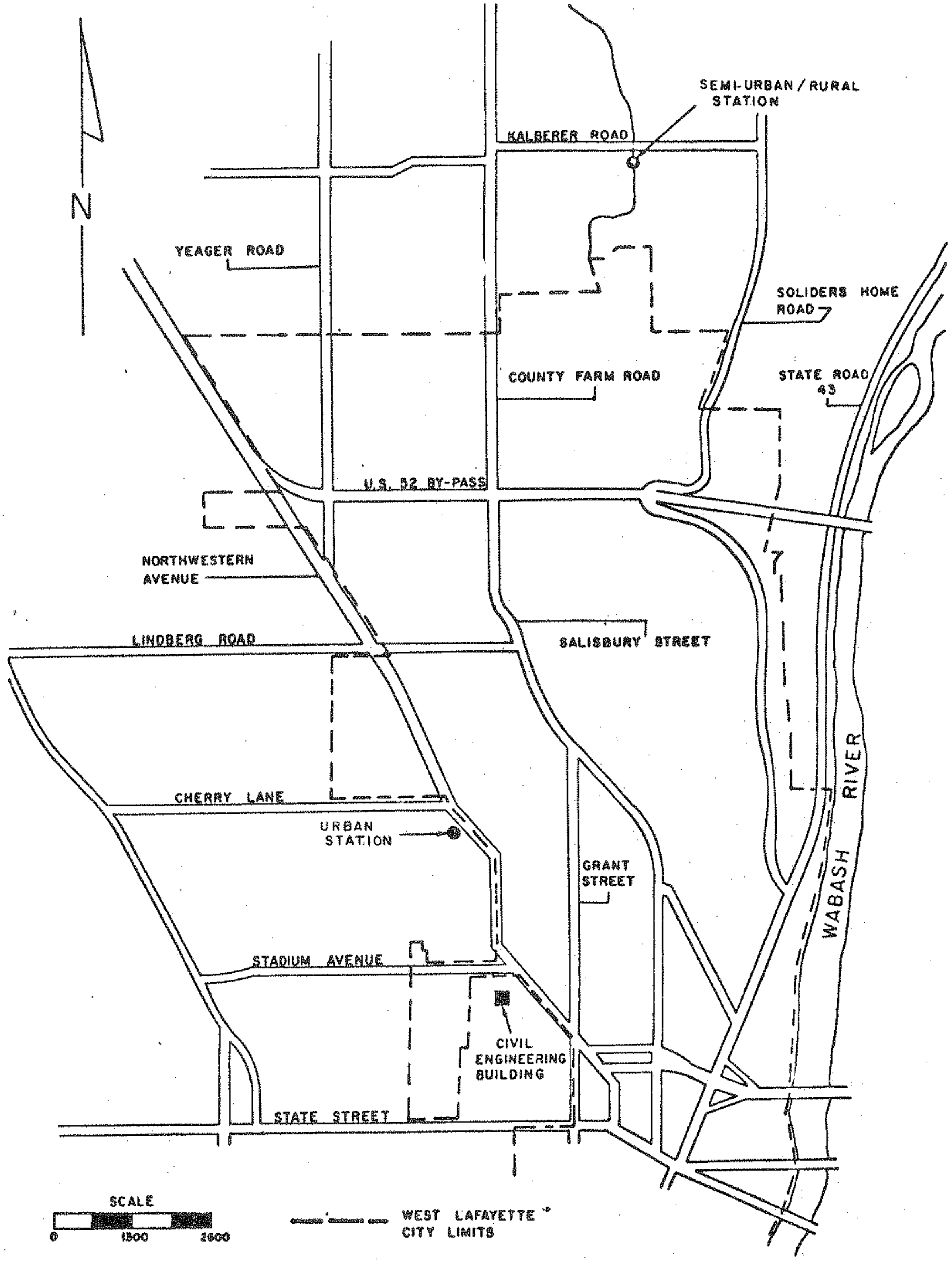

FIGURE 4 LOCATION OF SAMPLING STATIONS AND THE CIVIL ENGINEERING BUILDING

on a factor of 3.5 persons per dwelling (28), is approximately 252 persons or 8.7 persons per acre. Eleven acres of the watershed, or about 38 percent, are impervious. Paved areas, such as streets and driveways, make-up six acres of the impervious area while roof areas make-up the remaining five acres.(29) The urban watershed, its drainage system, and location of the gaging-sampling station are shown in Figure 5.

The gaging-sampling station is located at the northeast edge of the Purdue University campus just west of Northwestern Avenue and is shown in Figure 6. All sampling and runoff measuring instruments are located in a concrete pit. A trap door, at ground level, and a ladder provide access to the instruments located approximately 15 feet below on the floor of the pit. A second trap door, at the bottom of the pit, and ladder, provides access to the storm sewer. All samples of the urban runoff were taken from this sewer. At the gaging station, the sewer drains into a concrete flume which has a Columbus-type deep notch weir (6-foot crest length) located at the downstream end. The head on the weir is used for stage measurement which is measured from a stilling well adjacent to the weir.

A Leupold-Stevens A-35 continuous stage recorder with a 20-inch chart, a recording raingage, and a temperature recording unit, are also used at this station. The stage recorder

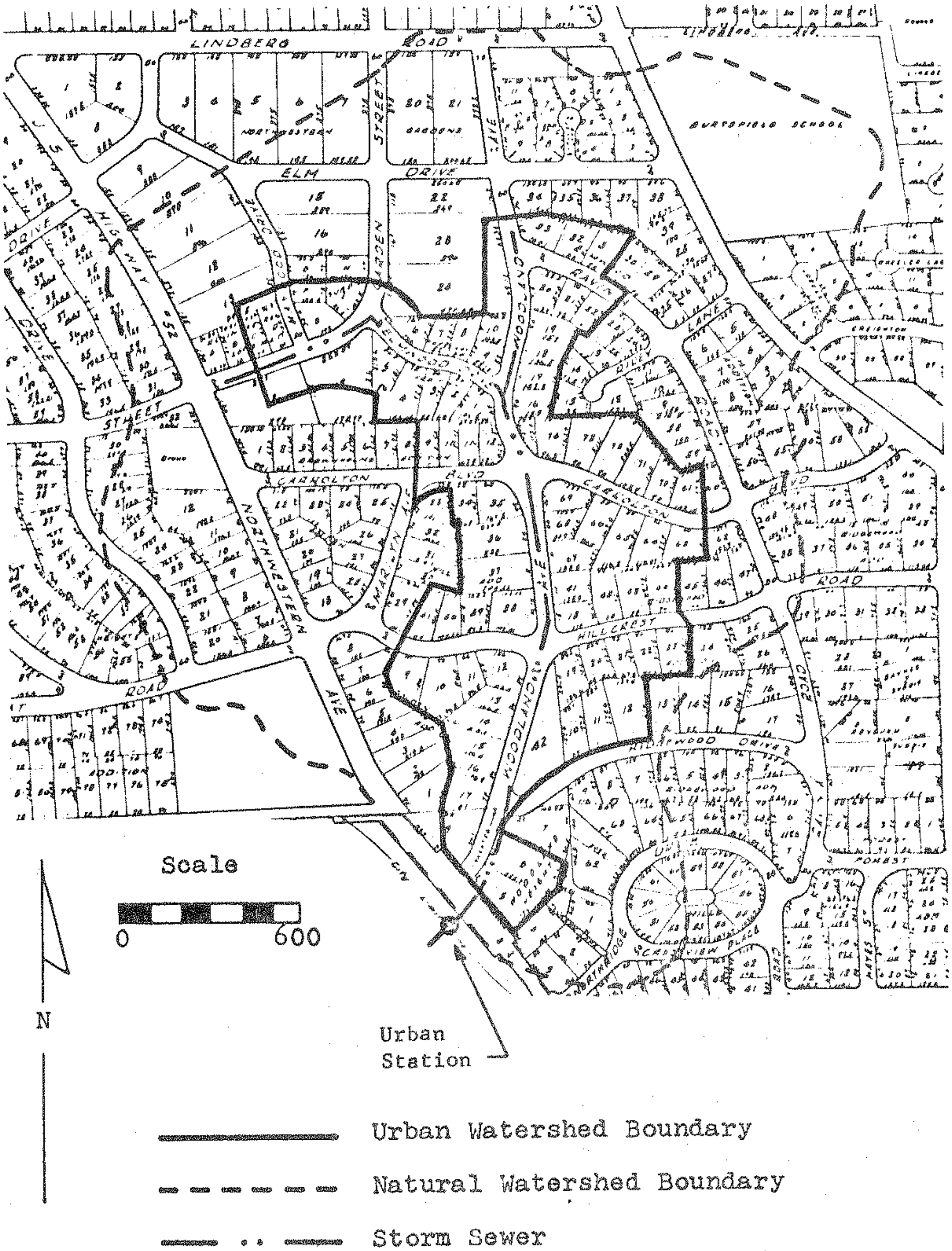

Figure 5 Urban Watershed and Sampling Station.

Figure 6. Photograph of Urban Gaging-Sampling Station.

A. Gaging-Sampling Station Pit

B. Northwestern Avenue (looking south)

is driven at a rate of 144 inches per day so that the stage values can be read at 1 minute intervals. A raingage, which has a 16-inch diameter rainfall receiver, and a temperature sensor, is mounted 8 feet above ground level. The cumulative rainfall, stage, and temperature values are recorded simultaneously on the same chart.

The sampling apparatus, which consists of a floatless liquid level control, power supply, and an automatic sequential composite sampler, is located in the pit. The floatless liquid level control is located in the stilling well adjacent to the Columbus-type weir. The sampler is located on the floor of the pit about six feet above the liquid level in the sewer. "Tygon" tubing extends from the sampler down into the storm sewer and the sample is collected in Mason jars located immediately under the sampler. (The entire sampling apparatus is described in detail in another section.)

Semi-Urban/Rural Watershed

The semi-urban/rural watershed, an area of 292 acres, includes a partially developed residential area and farm land. The area of the partially developed residential area is 178 acres and the farm land area is 114 acres. The watershed is located about 4 miles north of the Purdue University Campus, and extends in a south-north direction. The population of the combined watershed is approximately 1000 persons with the bulk of the population being in the partially developed residential area. The population density of the area is 3.4 persons per acre.

The location of the Semi-Urban/Rural Watershed gaging-sampling station is shown in Figure 7. The station is located approximately 2.5 miles north of the Purdue University Campus, about 150 feet upstream of a culvert at Kalberer Road and is shown in Figure 8.

The station has two Parshall flumes in the ditch and an instrument shelter located underground approximately 30 feet from the centerline of the drainage ditch. A Stevens Duplex 2A-35, 20-inch chart stage recorder, a recording raingage, a temperature recording unit and stilling wells, are housed in the 10-feet by five-feet by seven-feet precast concrete instrument shelter. A trap door at ground level and ladder provide access to the instruments. One of the Parshall flumes is 2-feet by 18-inches and measures flows up to 14 cfs while the other flume is 10-feet by 3-feet and measures flows over 14 cfs. Backwater effects, caused by replacement of a bridge at Kalberer Road, after calibration of the flumes, made it impossible to rely on flow data derived from these flumes. Therefore, flow measurements are made using Manning's equation and depths in the flume when the flow is above 14 cfs.

The instruments used at this station for measurement and recording of stage and rainfall are similiar to those at the urban watershed. In addition, an 18-inch long temperature sensing element is located 8-feet above the ground

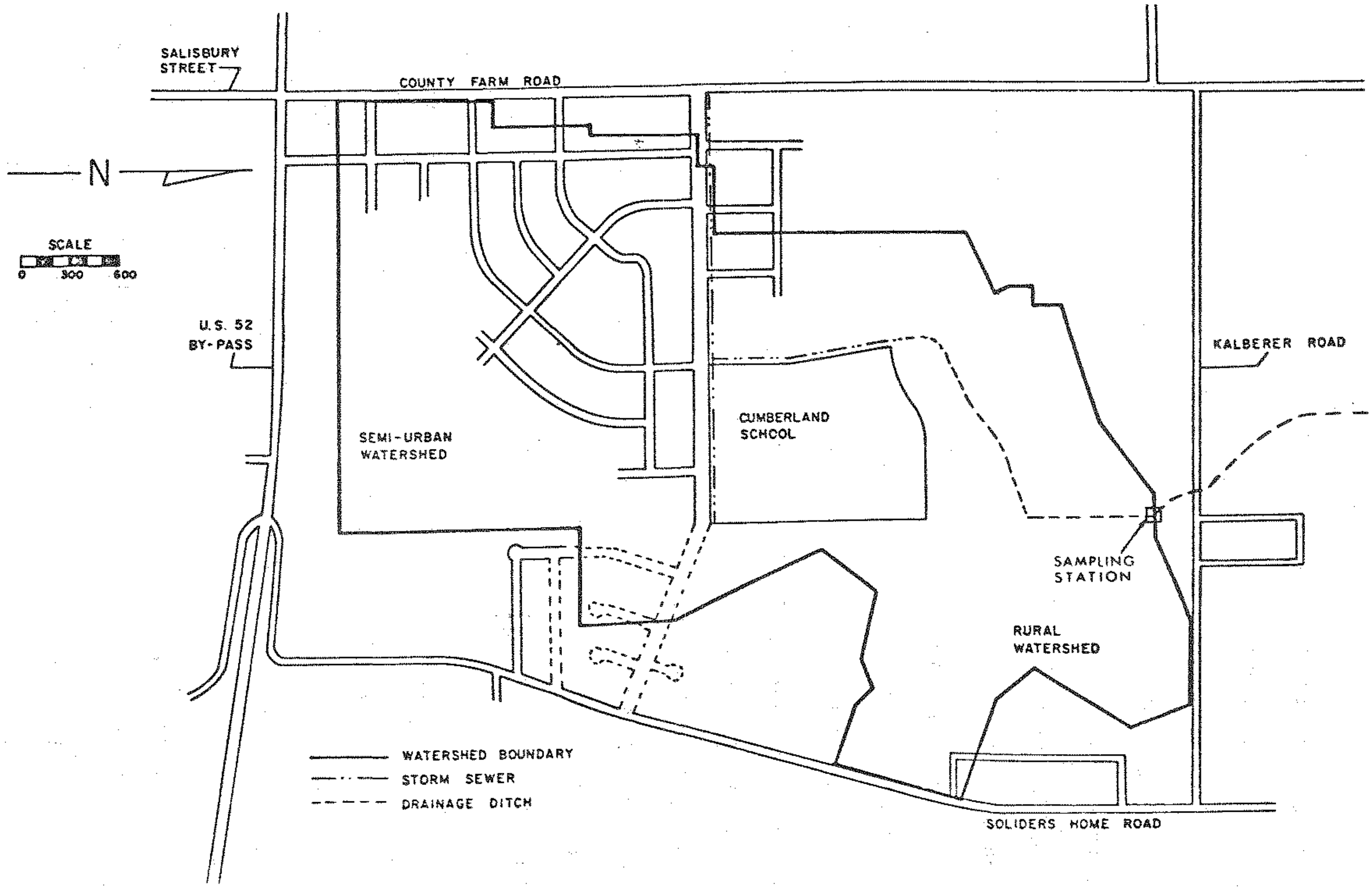

Figure 7. Combined Semi-Urban/Rural Watershed and Sampling Station.

Figure 8. Photograph of Semi-Urban/Rural Gaging-Sampling Station.

A. Parshall Flume in Drainage Channel

B. Drainage Channel

C. Gaging-Sampling Station Vault

D. Kalberer Road

level. The temperature is recorded by a Stevens temperature recording unit used with the stage recorder. The water stages in the two Parshall flumes, rainfall, and temperature are recorded simultaneously on the 20-inch chart at this station. Further, an "Evaporation Station", consisting of a 4-foot diameter evaporation pan, a maximum-minimum thermometer, an integrating anemometer to measure evaporation, temperature variation and wind velocities, respectively, are located at this station.

The sampling apparatus is located in the underground vault. It was necessary to build and install a stilling well in addition to the ones already present in order to use the floatless liquid level switch electrodes. The stilling well is a 4-inch by 3-inch by 6-feet poltethylene column which is connected with a galvanized tee to plumbing servicing the stilling wells used to measure flow. It was also necessary to install 35 feet of 3/8-inch diameter soft copper tubing one-foot underground leading from the stream to the inlet of the sampler in the vault. The sampling aparatus is identical to that used in the urban gaging-sampling station.

Description of the Sampling Apparatus

The sampling apparatus consisted of a Sentry Sequential Composite Sampler, a Charles F. Warrick Floatless Liquid Level Control, a Sears Model 28-7108 3-amp, 12-volt battery charger, and a isolation transformer. The Sentry Automatic Sequential

Composite Sampler was purchased from the N-Con Systems Company, Larchmont, New York, and is shown in Figure 9. The sampler consists of a peristaltic (squeeze tube) pump which can operate in either direction as a positive displacement pump or a purge pump and a programmable timer which can be pre-set by means of movable keys on a timing drum which moves at one revolution per hour. The three types of keys placed around the drum cause the sampler to purge, pump or deliver, and index to the next bottle.

The sentry can collect 24 250 ml composite samples over a period of 3, 6, 8, 12, or 24 hours with each sample being made up of 2 to 8 individual aliquots. The pump has a lift of up to 15 feet and is adjustable so as to provide full aliquot samples under all lift conditions. The Sentry is capable of purging itself after each aliquot. It can be operated by dry batteries, a storage battery or an optional AC/DC converter. In this study a Sears Model 28-7108 3-amp, 12 volt battery charger was used allowing the use of the AC current which is available at the sampling stations. The technical specifications for the Sentry Sampler are given in Table 25.

The sampler's inlet tube is placed in the stream or sewer to be sampled. The operator selects the desired number of hourly aliquot samples. Each time an aliquot sample is to be collected, the pump operates in reverse for a preset period to clear the inlet line. The pump then reverses

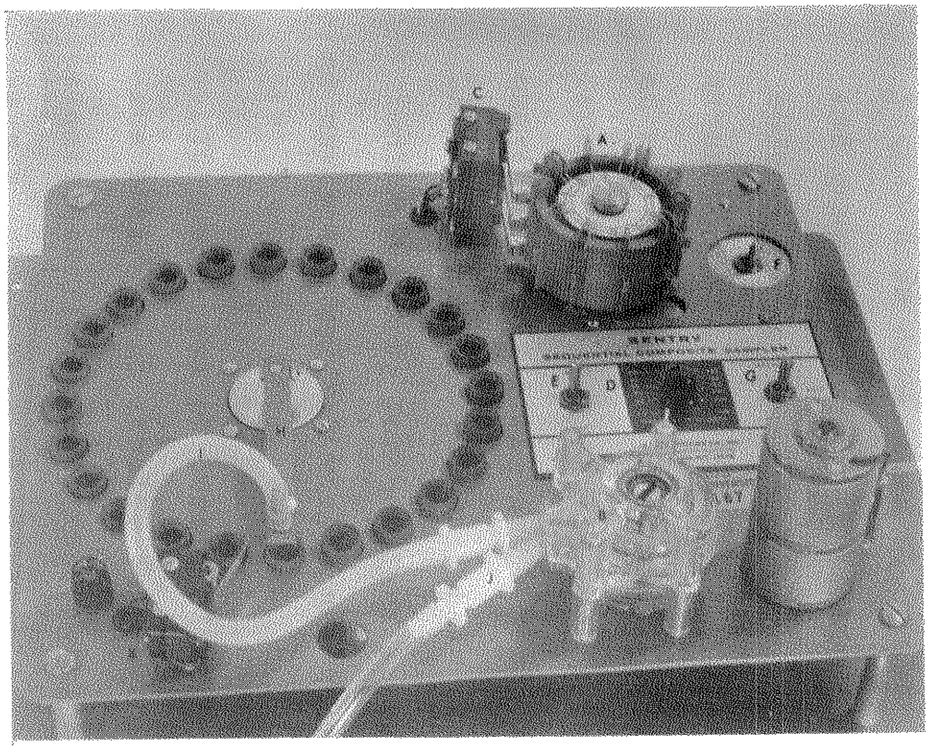

Figure 9. Photograph of Sentry Sampler.

A. Program timer and drum with keys in place
B. Peristaltic pump
C. Switch for stepper/pump/purge modes
D. Knob for setting pump running time
E. Main control switch
F. Selector switch for no time limit or 24 hour time limit.
G. Selector switch for test pump/automatic/test purge
H. Stepper arm (distributor arm)
I. Discharge tubing (to sample containers)
J. Suction tubing (to stream)
K. Stepper arm limit switch

Table 25

Sentry Sampler

Technical Specification

Control Switches

System on-off: Main control switch
Selector switch: Selects automatic or test operation

Program Timer and Drum

Timing drum speed: 1RPH
Keys set for 2, 4, 6, or 8 samples per hour, 24 bottles filled in 3, 6, 8, 12, or 24 hours (other time periods available)

Sample Delivery (Volume) Timer

Type: Solid state
Adjustment: Knob on main panel to set sample volume in accordance with sampling program and hydraulics of the installation

Pump Motor

Type: Brush type, 12-volt D.C. Totally enclosed non-ventilated

Pump

Type: Peristaltic (squeeze tube)

Material: Clear polycarbonate

Bearings: Low friction ball bearings

Tubing: Silicone rubber, 1/4" id x 3/8 O.D.

Liquid Velocity: 15 per minute

Lift: 15 feet

Flow Rate: 150 ml/minute

Power Supply

Type: 12-volt dry battery or storage battery (by others) or 110 VAC to RVDC converter (by others) and runs for the preset period to deliver sample to the proper bottle. After collecting the proper number of aliquot samples, the sample distribution arm automatically indexes to the next position.

It was necessary to reduce the number of samples from twenty-four to twelve due to limited space in the vault. It was also necessary to run through five pumping cycles of four minutes each purging only between samples rather than between aliquots in order to provide continuous sampling and approximately one liter per sample. Quart "Mason" jars were used for sample containers.

One of the main goals of automatic sampling is to deliver a representative sample as close to the time of occurrence as possible and to stop sampling when the event has passed. The Charles F. Warrick Floatless Liquid Level Control was acquired in order to start sampling with initial stormwater runoff. The level control consisted of a switch box, receptacle box, electrode fittings, and two brass electrodes. When the water level rose in the stilling well in response to an increase in flow in the storm sewer or drainage ditch so as to touch the two electrodes, a circuit was completed and the sampler is activated.

Due to the dampness associated with the vaults it was necessary to insulate as much of the electrical equipment as possible to insure the safety of those working in the instrument shelters. As an additional safety precaution, an isolation transformer was acquired from the Stancor Company to supply 110-volt A.C. free of reference to earth-ground, therefore reducing the chance for accidental shocks.

Figure 10 gives a schematic of the sampling equipment and Figure 11 is a photograph of the sampling equipment.

Installation of Samplers

Urban Watershed

The installation of the sampler at the urban station required very little alteration of the vault. Four 2-foot wooden legs were attached to the frame of the sampler so as to allow ample room for the Mason jars to be placed under the tubes hanging from the sampler. The two electrodes and the receptacle box used in conjunction with the floatless liquid level control were attached to a two-foot ring stand. The electrodes, measuring five feet in length, were then suspended down into the stilling well adjacent to the Columbus weir which reach almost five feet below the floor of the pit. Through the use of the ring stand it was possible to adjust the level of the electrodes in the stilling well as might be necessary with weather conditions for the purpose of activating sampler with initial runoff. Ten feet of "Tygon" tubing extends from the inlet of the sample, down the side of the access ladder into the storm sewer and is anchored to the ladder so that should swift currents develop the tubing and sampler would not wash away.

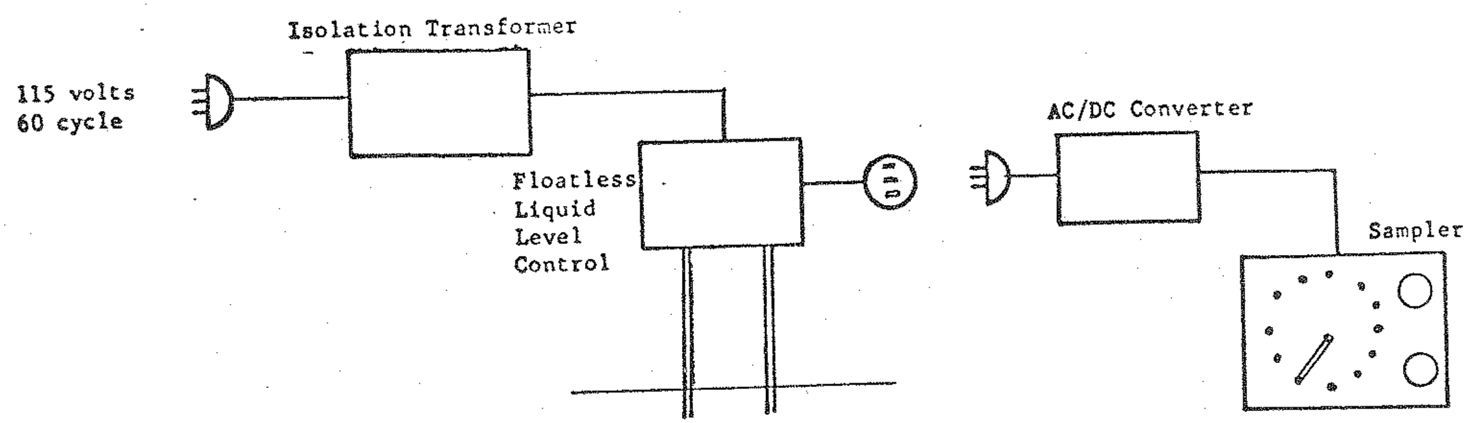

Figure 10. Schematic of the Sampling Equipment.

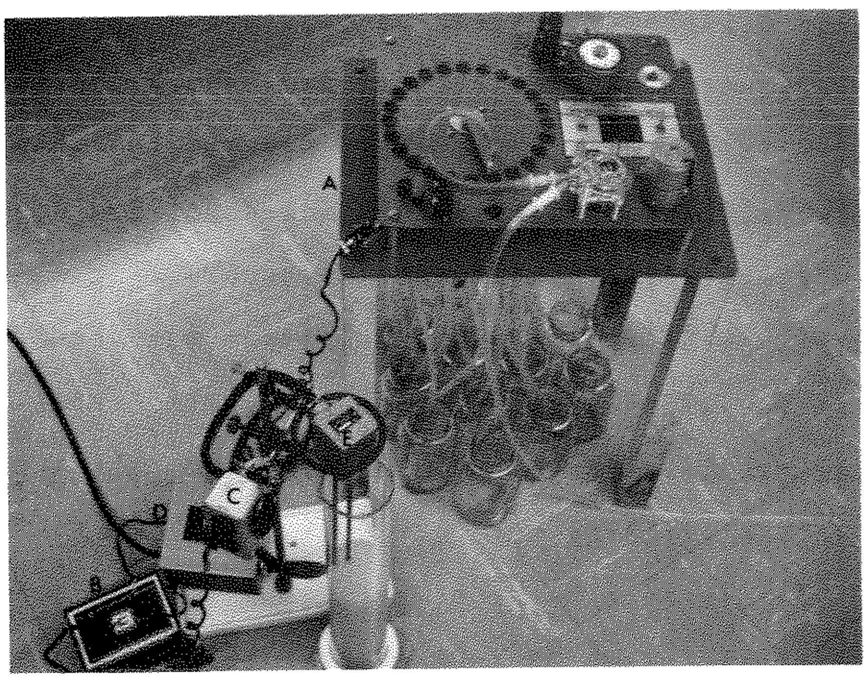

Figure 11. Photograph of Sampling Set Up.

A. Sentry sequential composite sampler
B. AC/DC Converter
C. Outlet
D. Floatless liquid level control
E. Electrode fitting and brass electrodes

Semi-Urban/Rural Watershed

The installation of the sampler at the semi-urban rural station required the construction of a 3-inches by 4-inches by 6-foot polyethylene column which serves as a stilling well. To install the stilling well it was necessary to modify the existing plumbing at the site by inserting a "T" at the piping running from the flumes to the existing stilling wells. A globe valve was installed in order to allow the removal of the polyethylene well at any time for maintenance without shutting down the other wells. (See Figure 12.)

It was also necessary to install shelving (2-foot by 3-foot) on which all electrical equipment, including the sampler, was placed at a height of 4-1/2 feet above the floor of the pit. This was done in order to prevent the sampler and other electrical equipment from being submerged during high flow in the stream which sometimes occurs.

The same type of ring stand arrangement was used at this station as at the urban station. The ring stand, when placed on the shelf, provided for proper adjustment of the two 6-foot electrodes in the stilling well.

Due to the distance between the stream and the sampler, it was necessary to place 35-feet of 3/8-inch (O.D.) soft copper tubing one-foot underground leading from the stream to the concrete pit. In order to place the tubing inside the pit, a 1/2-inch diameter hole was drilled through the 6-inch thick concrete wall of the pit at 1-1/2 feet below

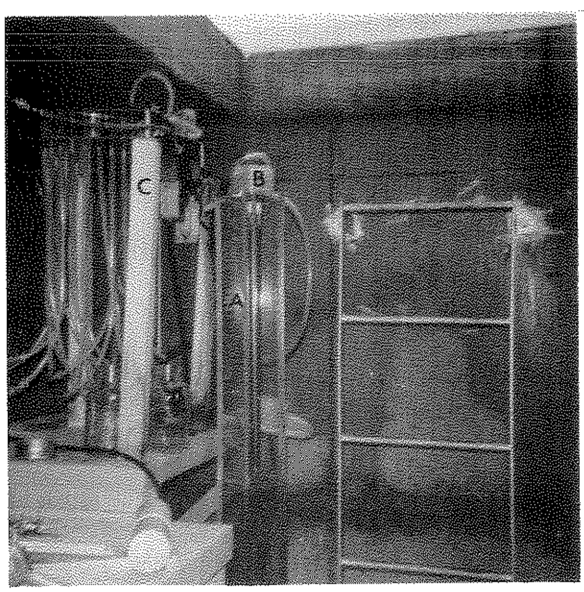

Figure 12. Photograph of Sampling Set Up Inside Vault At the Semi-Urban/Rural Station

A. Stilling well
B. Electrode fitting and brass electrode
C. Sampling equipment

the top of the precast concrete pit. (The top of the vault was about 6 inches above the ground.) After the copper tubing was placed through the hole, the hole was sealed to prevent water from leaking into the pit. The copper tubing was then connected to the inlet tubing of the sampler with a union compression fitting.

Operational Difficulties

One of the main sources of difficulty with the study was the sampling equipment. A great deal of time was spent in trying to devise a method of activating the sampler at initial runoff. Although the floatless liquid lever control was of enormous help in this respect, it was very difficult to adjust the level of the electrodes so as to achieve activation at initial runoff. A main reason for this problem was the storm pattern during the period in which the study was performed. The periods between rainstorms was small and when it rained it was of long duration and low intensity. Thus making it nearly impossible to discern between runoff peaks of individual storms. The level of the water in the stilling well was so high that it was necessary to set the electrodes far above base flow stage. Thus, if any recession in flow occurred from the time of setting the electrodes to the time runoff from another storm occurred, the flow would have to increase substantially before the sampler would start. First flush effects would be lost due to this time delay.

The runoff at the urban sampling stations is of a very flashy nature, in that the water level in the storm sewer rises and falls rapidly. The problem with electrode adjustment was especially difficult here. The only way to resolve such a problem was to constantly check the forecast and as close to the beginning of the storm as possible reset the level of the probes.

A problem developed with the timer and microswitch on the sampling station at the semi-urban/rural station. The keys on the rotating timer would lock on the microswitch in such a way as to impede or completely stop the timing drum from rotating. Thus after a series of operations were performed, or one pumping cycle was completed, the sampling operation would stop. A small adjustment of the microswitch and inspection of each individual key on the timing drum solved this problem.

Another problem at both stations was with the sampling hose that emptied the sample into the sampling container. Invariably, the hose connected to the distribution arm would come out its socket in the arm and empty the samples. This would occur on the last two samples of the series. This problem has not yet been solved though a great deal of thought has been given to it.

Still another difficulty with the sampler was the varying head differential. At low flow, or at initial runoff, the suction head is so great that the volume of sample is small. At high flow the volume of sample is larger due to a smaller head differential. It is crucial to obtain samples of initial flow for it is in the initial flow that high solids and BOD concentrations are normally found. It is important, therefore, to obtain a sufficient volume of sample to perform the desired analyses. The flexibility in the operation of the sampling equipment permitted a great deal of experimentation which eventually solved this problem.

SAMPLING METHODOLOGY

Introduction

One of the main objectives of this study was to outline the best sampling procedure for obtaining the water quality of the stormwater runoff of the watersheds. Some of the questions which had to be answered were: 1) How do limitations of the sampling equipment effect the sampling program? 2) What is the longest duration desired for a single set of samples? 3) Is there a relationship between the intensity and/or duration of rainfall and the duration of sampling? 4) Does the type of water quality analyses dictate the maximum sampling interval? 5) Does flow characteristics effect the sampling interval and duration? 6) After the samples have been obtained, what method can be used to determine which samples to analyze, if all samples can not be analyzed? Answers to these questions were necessary in order to outline a recommended sampling program.

Type of Samples

Stormwater runoff samples were collected using an automatic sequential composite sampler. A sequential composite is made up of a series of frequently collected samples that are composited and retained in individual containers each of which represents a sub-period within the overall sampling period. The flexibility of the sampling equipment (ability to adjust the length of a pumping cycle and the number of pumping cycles) permitted continuous sampling within the sub-period and thus over the duration of the entire storm.

In order to determine the magnitude of possible first flushing which occurs with initial runoff, the sampler must be activated with initial runoff. Due to the fact that forecasting rainfall and resulting runoff to an exact point in time was not possible, automatic sampling equipment was deemed necessary. Also, due to the distance between the sampling stations, and the fact that sampling had to be done over the entire duration of the storm, automatic samplers were required in order to compare the pollution parameters during the same storm for the two test watersheds.

Grab sampling only allows one to choose individual events which may or may not represent the important events occurring during the storm. Grab samples must be taken frequently and, if done automatically, at some regular interval. It is quite possible, therefore, to completely miss peak characteristics or extreme variations in pollutional characteristics of the stormwater runoff.

It is impossible to determine from samples composited over a long period the occurence of significant changes in water quality during the period as well as to when such events occur, what happens and when. A composite may also contain self-cancelling occurrences or may dilute significant slugs of pollution so that they are missed.

Therefore, due to the inadequacies of manual sampling and the inability to accurately describe the stormwater runoff quality, variations using either grab or long-term composite samples, automatic sequential composite samplers were used in this study.

Sampling Interval

The sampling equipment used in this study had several limitations which affected the sampling program. One of these limitations was the minimum sampling interval attainable with the sampling equipment. The minimum sampling interval attainable was fifteen minutes. Even if a smaller sampling interval were possible, it would be impractical because the sampling equipment would have to be reset too often, thus losing the benefits of automatism.

The types of analyses performed on the samples were a critical factor in deciding the sampling interval. Suspended solids concentration changes rapidly in stormwater runoff. In order to best describe exactly how the suspended solids vary with flow, the smallest interval possible should be used. Many studies indicate that effects of "first flushing" are transcient and could be dampened out in composites as small as one hour. BOD concentration also varies throughout the storm but not as dramatically as suspended solids concentration.

Due to the lack of space in the instrument shelter, only twelve samples could be taken before the sampling equipment had to be reset. Considering the fact that bacterial samples should be analyzed as soon as possible and that the sampling equipment did not have a refrigeration unit, the time that a sample remained in the instrument shelter was reduced to a minimum. This meant that the sampling interval had to be kept to as small a value as possible.

Another factor which influenced the sampling interval was how well the instantaneous flow data could be duplicated using mean flow data over some time period. In other words, would the shape of the flow hydrograph be altered substantially if some time interval such as a mean hourly flow or mean half-hour flow were used instead of instantaneous data? Due to the "flashy" nature of the flow at the urban sampling station, it was necessary to keep mean flow period down to one half-hour or less in order to best duplicate instantaneous flow data.

Sample Volume

The sample volume was dependent on the limitations of the sampling equipment, flow characteristics, and the sampling frequency which is determined by the sampling interval. In order to perform total and fecal coliforms, BOD, and suspended solids analyses, a sample volume of at least one liter was desired.

It was found that, at the hydraulic heads involved at both stations, it was necessary for the sampler to purge for one minute and to pump for twenty minutes (or five four-minute pumping cycles). After purging, which completely emptied forty feet of tygon tubing in one minute, one full four minute pumping cycle was required to deliver a sample taken at the stream to the composite container located in the pit at the Semi-Urban/Rural Sampling Station. The four remaining cycles were required to deliver sufficient volume for analysis. In other words a fifteen minute sampling frequency could not deliver enough volume for the intended analyses on each sample collected.

The same type of conditions existed at the Urban Sampling Station but the influence of rapidly varying flow at this station also effected the volume of sample. At low flow the hydraulic head was so great that the volume delivered was reduced greatly from that delivered at high flow.

Sampling Duration

The flow hydrograph characteristics relate closely to the intensity and duration of rainfall. The duration of significant runoff was dependent on the duration of rainfall and time of peak flow was dependent on the intensity and the duration. The investigator had no way of obtaining intensity and duration data of a storm prior to the storm, so his observations during the storm helped him to decide when to stop sampling on the basis of intensity (which affect time of peak runoff) and duration (which may affect time of peak as well as duration of significant runoff).

Sampling Program

The sampling interval chosen, considering all the factors, was a half-hour interval. This meant that if twelve samples were taken, the sampling equipment had to be reset every six hours until the investigator decided to stop the sampling of a particular storm. The volume of sample varied from 500 ml to 1000 ml.

The sampling interval and the number of samples to be collected were preset before the storm and remained constant during this storm. The tremendous advantage to this was that one could continue to sample over the entire duration of runoff and decide at some time after the storm which samples to analyze.

It was important that as many samples as possible be taken so as to best describe the quality of the runoff. However, it was realized that not all samples collected could be analyzed because of the tremendous number of samples generated by each storm. It thus became evident, that some choice had to be made as to a method to decide which samples to analyze.

One solution would be to analyze samples at regular intervals. This method, however, may miss significant transient events. The method decided upon was rather subjective and relied on the investigator's ability to visually isolate important transient, as well as long lasting, events.

If in a set of samples taken during a storm a significant variation in turbidity occurred, a sample, or a series of samples, would be analyzed where this variation occurred' so as to best describe the variation. If the variation was a sudden increase in turbidity that lasted for only a short period samples would be analyzed on the half-hour until conditions stabilized. If the turbidity increased and remained fairly stable, only one or two samples were analyzed depending on the length of this stable period. When turbity was low and remained low, samples were examined every two hours. When stable conditions returned, samples were analyzed every two or three hours. The investigator's decision of what constitute low or high turbidity and a stable condition was purely subjective, but because of the dramatic nature of variations at the watershed it was felt that this method was entirely adequate.

Analyses Selection

The analyses performed in this study were chosen on the basis of their importance in characterizing the quality of the runoff, the relative ease in which they could be performed, and their frequency of appearance in the literature.

The basis for the selection of the majority of the analyses was the acceptance of these tests by water pollution researchers as being basic indicators of pollution. Not all of these analyses could be performed, however, due to the huge number of samples resulting from one storm and the frequency of storms sampled.

The analyses originally considered for the study were total and suspended solids, total and fecal coliforms, and BOD. These were the analyses most often reported in the literature. Total and fecal coliforms were originally analyzed but were abandoned due to the tremendous amount of time required to perform these analyses. Suspended solids and BOD were the routine analyses performed on the samples.

All sample analyses were performed in accordance with the methods and procedures given in Standard Methods for the Examination of Water and Wastewater, Thirteenth Edition. (30) The multiple tube fermentation method of the coliform test was used in this study.

PRESENTATION AND DISCUSSION OF DATA

Introduction

This section discusses each storm monitored at the test watersheds (urban and semi-urban/rural) and compares the two watersheds for several storms. The flow pattern for each storm is discussed with regards to its relationship to the shape of the graphs of BOD and suspended solids concentration and mass emission. The peak values for flow, BOD and suspended solids concentration and mass emission are presented in tabular form at the end of the discussion of each storm.

A comparison of the two watersheds requires the derivation of a factor which will reduce the two watersheds to an equitable basis. The flow hydrographs and the pollutographs for BOD and suspended solids are compared along with a comparison of the relative magnitude of the concentration of BOD and suspended solids found. The watersheds were also compared on the basis of fluctuations in BOD and suspended solids concentration and the presence or absence of "first flush" effect.

Quality of Dry Weather Flow

The pollution level that existed in the drainage ditch and storm sewer during periods of dry weather flow was determined before sampling began.

Samples of dry weather flow were obtained on October 16, 1972, at the urban station and the combined station. The results of the analyses for the urban station were 3.6 mg/l BOD and 10 mg/l suspended solids. For the combined station the results were: BOD < 2.0 mg/l and suspended solids equal to 17 mg/l. This data shows that the pollution in dry weather flow was very small for this day and it was assumed that the pollution level in flow prior to runoff in other storms was also low.

Urban Watershed Storms

Storm of October 27, 1972

The stormwater runoff quality data obtained during this storm is presented in Table 26. The peak flow was extremely low (.052 MGD) but due to the high concentration of suspended solids and BOD associated with this flow, the pounds of pollutants produced was relatively high. The concentration of BOD and suspended solids followed the same basic pattern established by the flow as can be seen from Figure 13. When flow increased, the concentration increased and thus the mass emission increased. Peak flow, peak concentration, and peak mass emissions occurred simultaneously. Coliform densities ranged from > 500 to 240,000 organisms per ml for total coliform and from 930 to 93,000 organisms per ml for fecal coliforms. Table 27. lists the peak values for flow,

Table 26

Stormwater Runoff Data for the Urban Watershed

October 27, 1972

Time	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day	Total Organisms / ml	Fecal Organisms / ml
7:38 PM	.0460	83	29.7	31.817	11.385	15,000	930
8:08 PM	.0368	30	15.0	9.200	4.600	150,000	93,000
8:38 PM	.0308	34	12.55	8.727	3.221		
9:08 PM	.0247	20	10.80	4.117	2.223	24,000	24,000
9:38 PM	.0190	20	9.03	3.167	1.430	21,000	21,000
10:08 PM	.0141	28	3.96	3.290	.465	93,000	43,000
10:38 PM	.0112	12.8	4.00	1.195	.373		
11:08 PM	.0100	8	6.19	.667	.516		
11:38 PM	.0090	13	5.50	.975	.412	240,000	210,000
12:08 AM	.0080	9	4.73	.600	.315		
12:38 AM	.0075	6.5	6.00	.406	.375		
1:08 AM	.0070	6.0	6.96	.350	.406	7,500	7,500

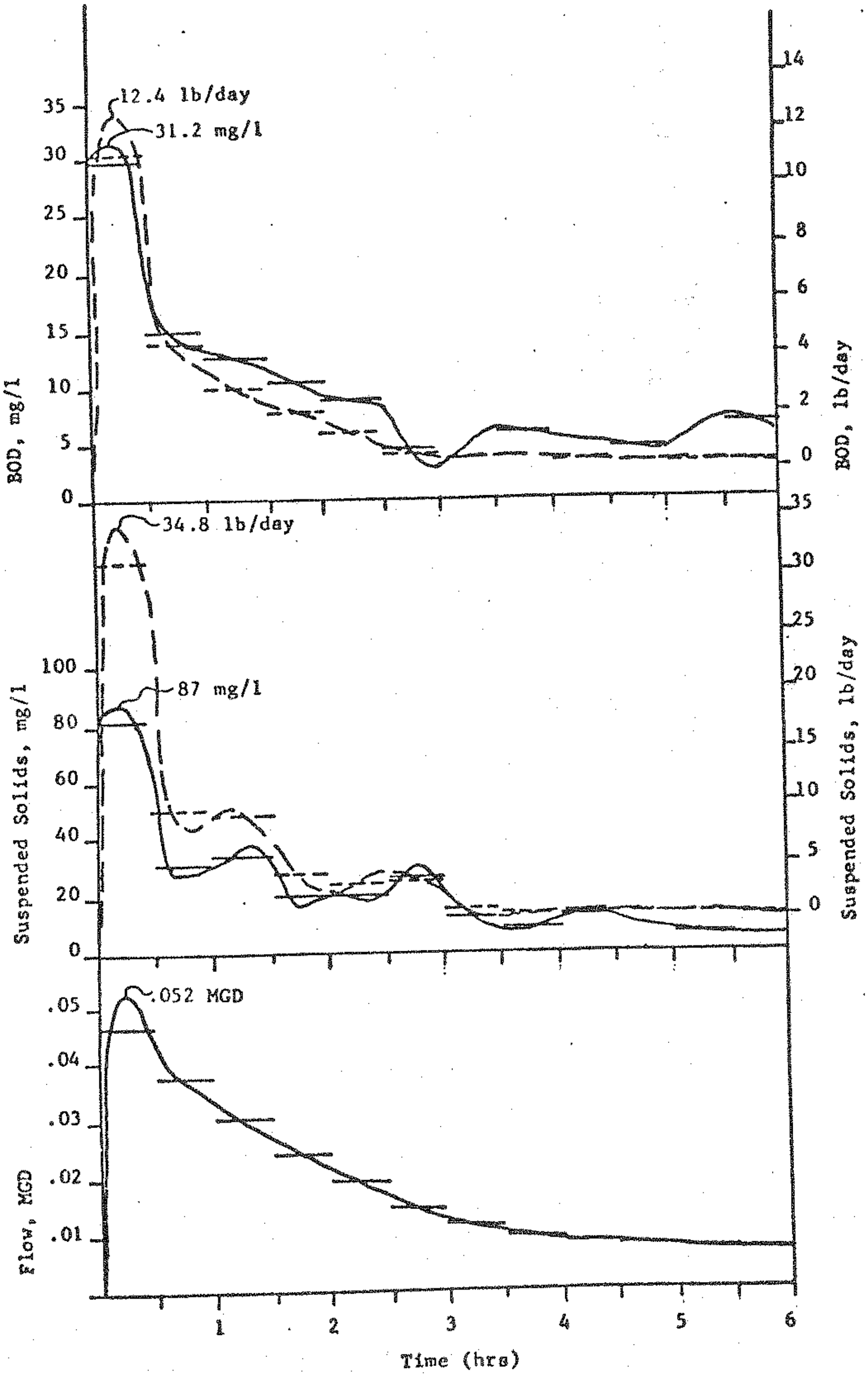

Figure 13. Variation in Flow, BOD, and Suspended Solids During the Storm of Oct. 27, 1972 at the Urban Sampling Station.

concentration, and mass emission which occurred during the storm.

Table 27

Magnitude and Time of Peak of Flow, BOD, and Suspended Solids for Storm of October 27, 1972 at the Urban Sampling Station

Parameter	Time After Initial Flow (Hr.)	Peak
Flow	.25	.052 MGD
BOD	.25	31.2 mg/1
BOD	.25	12.4 lb/day
S.S.	.25	87.0 mg/1
S.S.	.25	34.8 lb/day

Storm of October 31, 1972

The data generated by this storm of relatively low run-off point out some very interesting features of this water-shed (See Table 28 and Figure 14). The automatic sampling equipment was arranged in such a way that the slightest in-crease in flow would initiate the sampling sequence. The samples which occurred during this very low initial flow had very high concentrations indicating a "first flush" effect. Peak concentrations of BOD and suspended solids occurred during the first hour of flow (See Table 29). Another feature was that, though the concentration was very high, the resulting poundage during this period was relatively small due to the extremely low flow.

Table 28

Stormwater Runoff Data for the Urban Watershed

October 31, 1972

Time	Flow MGD	S.S. (mg/1)	BOD mg/1	S.S. 1b/day	BOD 1b/day	Total organisms / ml	Fecal organisms / ml
9:42 AM	.0010	67	28.2	.558	.235	150,000	93,000
10:12 AM	.0013	31	34.2	.336	.370	930	430
10:42 AM	.0014	24	27.5	.280	.321		
11:12 AM	.0013	23	19.8	.249	.214		
11:42 AM	.0013	26	19.0	.282	.206		
12:12 PM	.0013	23	19.0	.249	.206	39,000	23,000
12:42 PM	.0014	15	19.0	.175	.222		
1:12 PM	.0047	40	19.05	1.567	.746	24,000	24,000
1:42 PM	.0200	46	18.95	7.667	3.158		
2:12 PM	.0274	26	18.70	5.937	4.270		
2:42 PM	.0278	62	18.45	14.363	4.274		
3:12 PM	.0264	20	18.00	4.400	3.960		
3:42 PM	.0225	38	17.10	7.125	3.206	9,300	2,400
4:12 PM	.0222	11	19.00	2.035	3.515		
4:42 PM	.0212	9	>24	1.590	>4.240		
5:12 PM	.0190	11.7	>22.5	1.852	>3.562		
5:42 PM	.0180	16	>22.5	2.400	>3.375		
6:12 PM	.0180	15.7	>22.5	2.355	>3.375		
6:42 PM	.0170	12	>22.5	1.700	>3.188		
7:12 PM	.0111	19.5	>22.5	1.804	>2.081		
7:42 PM	.0051	36	>22.5	1.530	> .956		
8:12 PM	.0040	32	>22.5	1.067	> .750		
8:42 PM	.0042	28	>22.8	.980	> .798		

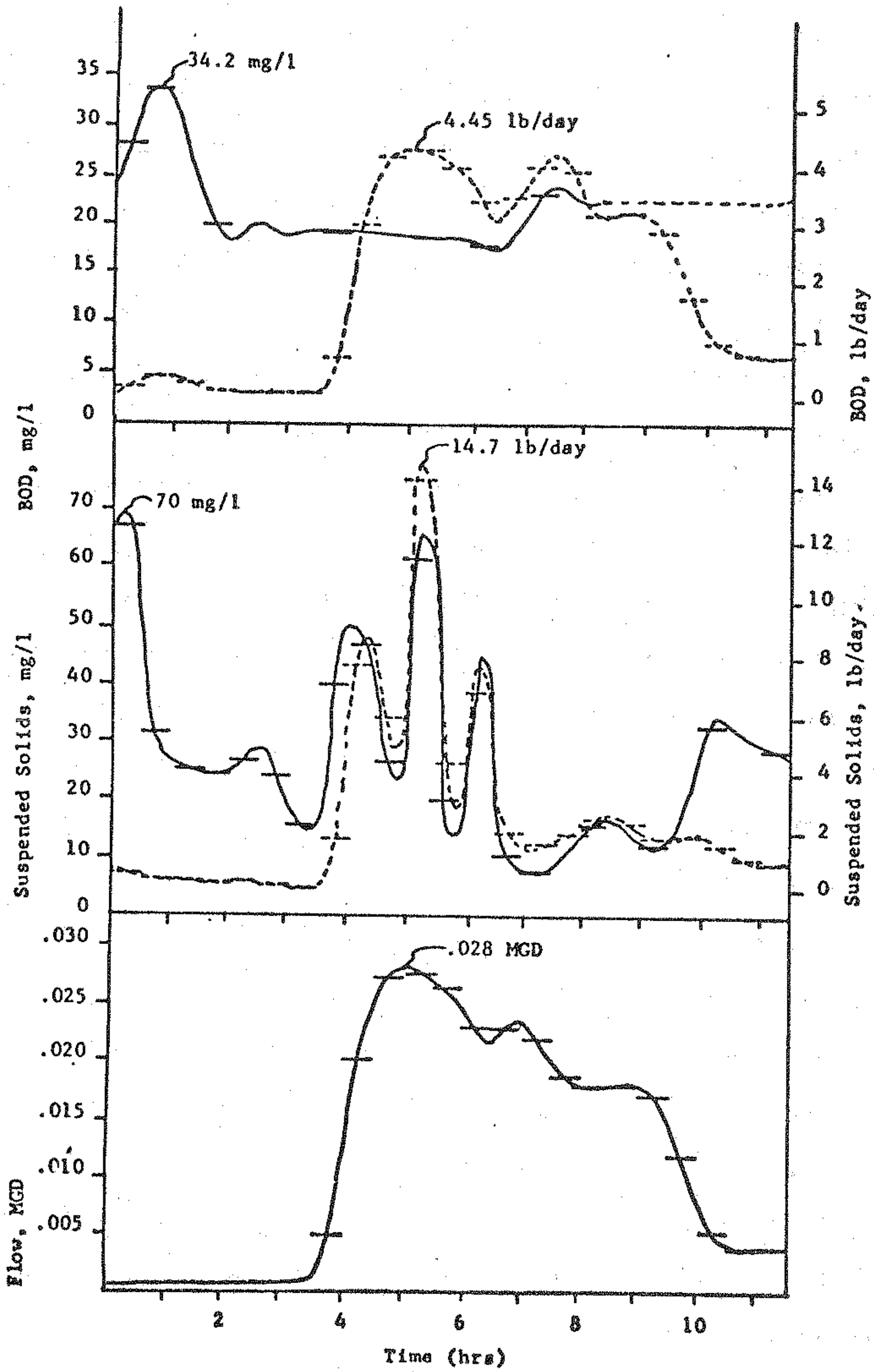

Figure 14. Variation in Flow, BOD, and Suspended Solids During the Storm of Oct. 31, 1972 at the Urban Sampling Station.

After three hours of low flow conditions the flow increased dramatically and peaked after five hours at .028 MGD. As the flow increased, the suspended solids, concentration increased but the BOD remained constant (See Figure 14). This results in yet another characteristic of the particular watershed, which is that the flow that caused the original "first flush" was not sufficient enough to flush the solids completely and the solids remained until such time as the flow was great enough to remove the major portion of the solids. This suggests that there may be some minimum flow which is required before the solids will be completely flushed. This minimum flow is dependent on several factors such as rainfall intensity and duration, antecedent dry period, etc.

The concentration of suspended solids at peak flow was 65 mg/l which is very close to the peak suspended solids concentration during the storm (See Figure 14). BOD was flushed with low flow and peaked one hour after peak flow. The BOD concentration after eight hours of flow was quite high but, due to errors in analyses, no value was found. Total and fecal coliform densities ranged from 930 to 150,000 organisms per ml and 430 to 93,000 organisms per ml, respectively. Table 29 summarizes the peak values which occurred during this storm.

Table 29

Magnitude and Time of Peak of Flow, BOD, and Suspended Solids for Storm of October 31, 1972 at the Urban Sampling Station

Parameter	Time After Initial Flow (Hr.)	Peak
Flow	5 Hr.	.028 MGD
BOD	1 Hr.	34.2 mg/l
BOD	5 Hr.	4.45 lb/day
S.S.	.25 Hr.	70 mg/l
S.S.	5.5 Hr.	14.7 lb/day

Storm of November 1, 1972

The values of flow and mass emission for this storm were the maximum recorded of all the storms monitored at the urban station (See Table 30). The flow peaked at a flow rate of 1.0 MGD. It can be seen from Figure 15, that the initial runoff did not seem to produce as much of a "first flush" of solids as did other storms and, though the concentration of BOD was greatest with initial flow, the concentrations were relatively constant and low throughout the storm. The BOD concentration decreased slowly from its initial value until the flow increased dramatically at which time the BOD increased. A seond peak of BOD concentration occurred at the same time as the peak suspended solids concentration. This second peak of suspended solids concentration followed the peak flow by one full hour and occurred with a

Table 30

Stormwater Runoff Data for the Urban Watershed

November 1, 1972

Time	Flow MGD	S.S. mg/l	BOD mg/l	S.S. lb/day	BOD lb/day	Coliforms Total organism/ml	Coliforms Fecal organism/ml
4:00 AM	.040	19	10.76	6.33	3.587		
4:30 AM	.105	16	10.05	14.00	8.794	93,000	43,000
5:00 AM	.157	13	8.81	17.01	11.526		
5:30 AM	.182	23	9.30	34.88	14.110		
6:00 AM	.168	32	9.83	44.80	13.760	24,000	9,300
6:30 AM	.145	21	9.10	25.37	11.000		
7:00 AM	.226	13	7.28	24.48	13.710	240,000	43,000
7:30 AM	.064	15	6.30	8.00	3.360		
8:00 AM	.050	26	6.23	10.83	2.596		
8:30 AM	.078	16	6.53	10.40	4.244		
9:00 AM	.154	11.5	6.48	14.76	8.316		
9:30 AM	.083	11	5.26	7.608	3.638		
10:00 AM	.045	10	4.52	3.75	1.695		
10:30 AM	.246	8	4.28	16.40	8.774		
11:00 AM	.554	7.5	4.45	34.62	20.544		
11:30 AM	.601	8.2	5.10	41.07	25.54		
12:00 PM	.337	16	5.88	44.93	16.51		
12:30 PM	.439	57	7.10	208.52	25.97		
1:00 PM	.504	54	8.08	226.80	33.94		
1:30 PM	.244	19	6.66	38.63	13.54	93,000	43,000
2:00 PM	.354						
2:30 PM	.283						
3:00 PM	.132						
3:30	.079						

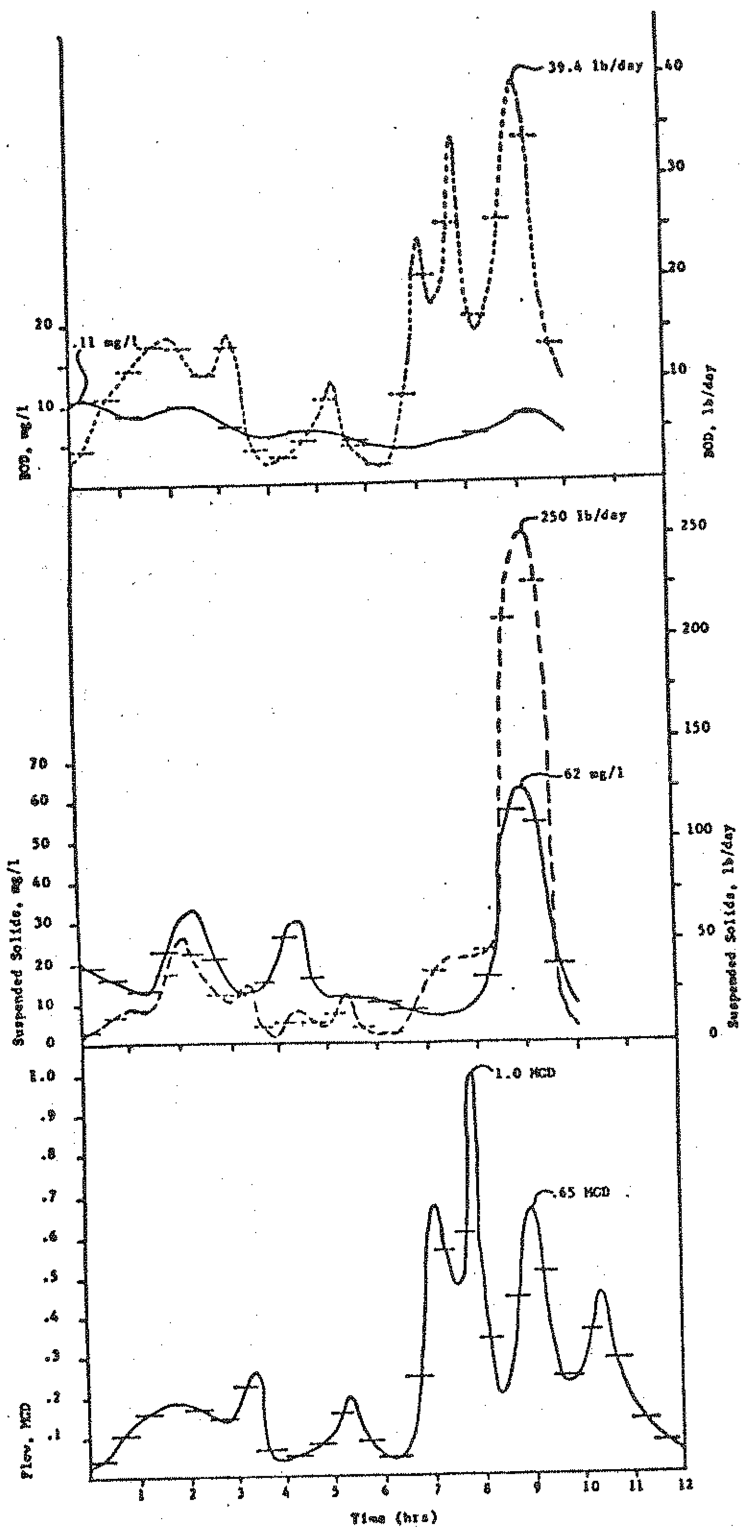

Figure 15. Variation in Flow, BOD, and Suspended Solids During the Storm of Nov. 1, 1972 at the Urban Sampling Station.

secondary peak flow. The suspended solids concentration reached 62.5 mg/1 at this time, compared to a concentration of only 20 mg/1 with initial flow. The suspended solids concentration followed the flow hydrograph more closely than BOD with peaks occurring near or at the same time as peaks in the flow hydrograph (See Figure 15). The total and fecal coliform densities ranged from 24,000 to 240,000 and 9,300 to 43,000 organisms per ml, respectively.

The pollutograph for BOD was influenced greatly by the flow hydrograph. Secondary peaks in flow were reflected in the pollutograph. This was due to the fact that the concentration of BOD was relatively constant. The pollutograph for suspended solids was not influenced as much by the flow hydrograph because of the high variance in suspended solids concentration. The peak suspended solids concentration at peak flow greatly effected the shape of the pollutograph and dampened the effects of secondary peaks in flow on the shape of the pollutograph. The values for the peaks in flow, concentration, and mass emission are given in Table 31.

Table 31

Magnitude and Time of Peak of Flow, BOD and Suspended Solids for Storm of November 1, 1972 at Urban Sampling Station

Parameter	Time After Flow Starts (Hr.)	Peak
Flow (Primary Peak)	7.8 Hr.	1.000 MGD
Flow (Secondary Peak)	9.1 Hr.	.65 MGD
BOD (mg/1)	.83 Hr.	11 mg/1
BOD (1b/day)	9.0 Hr.	39.4 1b/day
S.S. (mg/1)	8.9 Hr.	62 mg/1
S.S. (1b/day)	8.9 Hr.	250 1b/day

Storm of November 13, 1972

The maximum values of concentration for BOD and suspended solids were recorded during this storm (See Table 32). The mass emission of pollutants was second only to the November 1 storm. Though the flow was much lower during the storm, the concentration of BOD and suspended solids was so high that the mass emission rates were similar to peak values found in the November 1, 1972 storm.

As can be seen from Figure 16, the flow peaked early in the storm at about 0.155 MGD and again about seven hours later at 0.485 MGD. The suspended solids concentration peaked with the first amount of flow in a pronounced "first flush" effect. The suspended solids decreased from first flush and then peaked again with the first peak in flow mentioned above. It appears that for this storm, 0.155 MGD was sufficient to flush the solids from the sewer and/or watershed in the vicinity of the sampling station, because after this flow suspended solids remained constant even when flow increased to its maximum level.

The peak suspended solids concentration at "first flush" was 250 mg/l. The concentration at the first peak in flow was high enough (87 mg/l) to cause the poundage to be greater at this time than at peak flow (106 lb/day compared to 100 lb/day).

The BOD concentration peaked at 44.5 mg/l two hours after runoff started. When the first peak in flow occurred,

Table 32

Stormwater Runoff Data for the Urban Watershed

November 13, 1972

Time	Flow (MGD)	S.S. (mg/1)	BOD (mg/1)	S.S. (1b/day)	BOD (1b/day)
8:08 AM	.004	238	20	7.933	.67
8:38 AM	.012	114	35.48	11.400	3.54
9:08 AM	.025	158	43.25	32.917	9.01
9:38 AM	.037	60	31.86	18.500	9.82
10:08 AM	.072	43.5	24.90	26.100	14.94
10:38 AM	.132	65.0	23.40	71.500	25.74
11:08 AM	.152	82	21.50	103.87	27.23
11:38 AM	.087	52	20.00	37.70	14.50
12:08 PM	.031	46	19.50	11.88	5.04
12:38 PM	.011	38	27.80	3.48	2.55
1:08 PM	.021	29	29.00	5.08	5.08
1:38 PM	.033	22	23.40	6.05	6.44
2:08 PM	.039	28	21.00	9.10	6.82
2:38 PM	.043	28	21.50	10.03	7.70
3:08 PM	.039	25	23.95	8.12	7.78
3:38 PM	.059	27	24.40	13.28	12.00
4:08 PM	.134	33	10.67	36.85	11.92
4:38 PM	.132	34	8.40	37.40	9.24
5:08 PM	.139	28	8.40	32.40	9.73
5:38 PM	.271	24	8.41	54.20	18.99
6:08 PM	.436	21	8.42	76.30	30.59
6:38 PM	.331	31	8.43	85.51	23.25
7:08 PM	.219	29	8.65	52.92	15.79
7:38 PM	.279	27	8.87	62.78	20.62
8:08 PM	.187	20	8.99	31.17	14.01
8:38 PM	.121	17	9.10	17.14	9.18

Table 32, Continued

9:08 PM	.071	22	8.90	13.02	5.27
9:38 PM	.046	24	8.73	9.20	3.35
10:08 PM	.028				
10:38 PM	.019				
11:08 PM	.017				

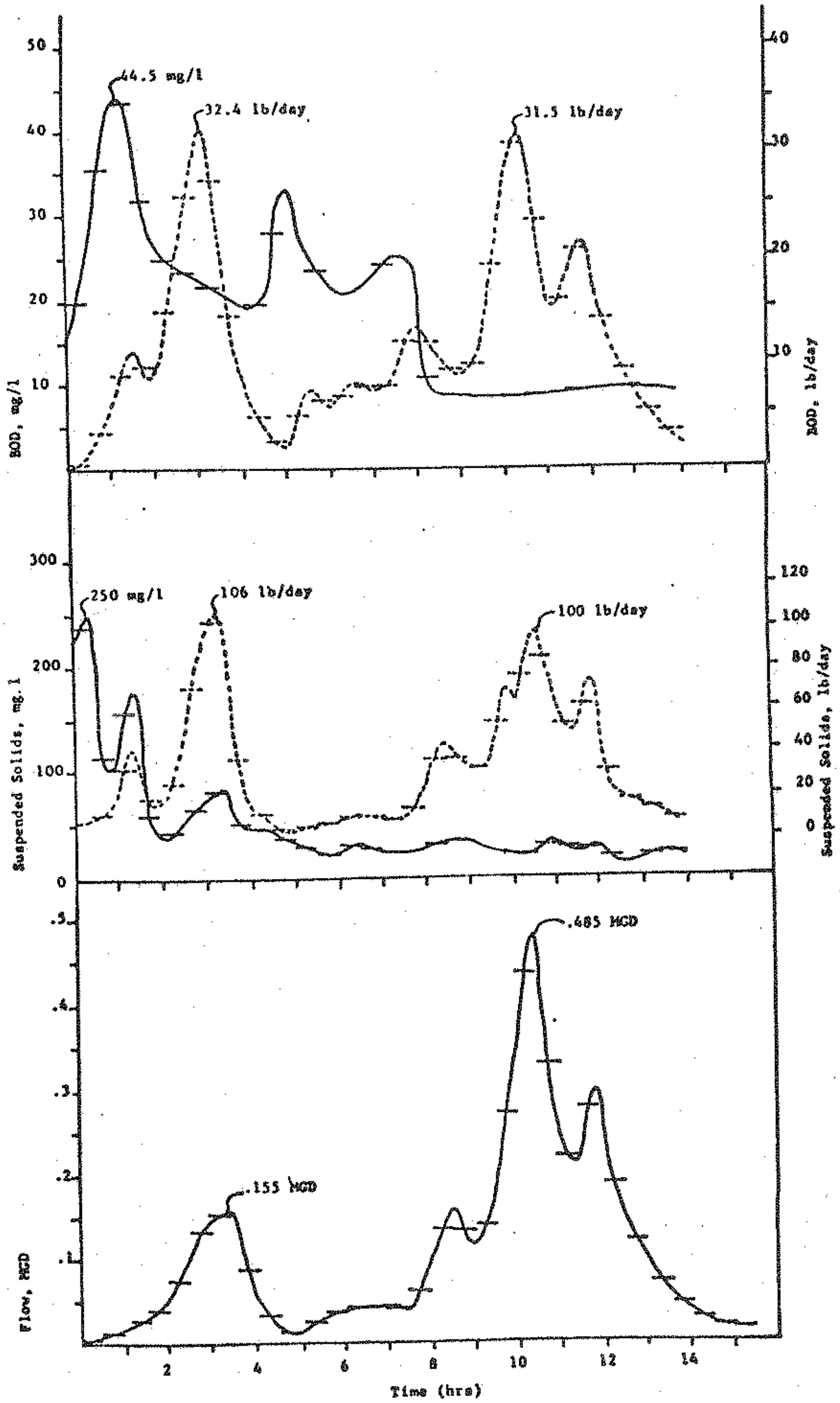

Figure 16. Variation of Flow, BOD, and Suspended Solids During the Storm of Nov. 13, 1972 at the Urban Sampling Station.

the concentration of BOD had decreased to a relatively constant value but when the flow increased toward the second peak, the BOD concentration dropped rapidly to a new low value and remained constant throughout the duration of the storm. Again, the concentration of BOD was high enough at the first peak in flow to cause the pollutograph peak to occur at the smaller flow rather than the peak flow (16.6 lb/day at smaller flow compared to 15.4 lb/day at peak flow). Table 33 summarizes the peak values found for this storm.

Table 33

Magnitude and Time of Peak and Flow, BOD and Suspended Solids for Storm of November 13, 1972 at the Urban Sampling Station

Parameter	Timer After Initial Flow	Peak
Flow (Secondary)	3.24 Hr.	.155 MGD
Flow (Primary)	10.40 Hr.	.485 MGD
BOD	1.25 Hr.	44.5 mg/l
BOD_1	3.00 Hr.	32.4 lb/day
BOD_2	10.40 Hr.	31.5 lb/day
S.S.	.25 Hr.	250 mg/l
$S.S._1$	3.00 Hr.	106 lb/day
$S.S._2$	10.40 Hr.	100 lb/day

Semi-Urban/Rural Watershed Storms

Storm of November 1, 1972

The data for this storm are given in Table 34. The flow peaked quite late in the storm as can be seen in Figure 17. The flow seemed to have little or no effect on BOD concentration and effected suspended solids concentration only at peak flow.

The BOD concentration was relatively low and constant throughout the runoff period (See Figure 17). There was very little peaking involved in this storm. However, the highest BOD did occur at the highest flow. There was no evidence of "first flushing" of BOD.

The suspended solids concentration increased dramatically, peaked, and decreased rapidly with peaking flow. The suspended solids concentration reached 54 mg/l at its peak (See Table 35). Again there was no evidence of "first flushing". Coliform densities ranged from 930 to 460,000 organisms per ml for total and from 930 to 4,300 organisms per ml for fecal.

The pollutograph for BOD matched the shape of the flow hydrograph exactly due to the fact that BOD concentration remained constant. The peak pounds of BOD per day occurred at peak flow and was 397 lb/day. The pollutograph for suspended solids was definitely effected by concentration but was only slightly effected by flow. The peak of suspended solids in pounds per day occurred at the same time

Table 35

Stormwater Runoff Data for the Semi-Urban/Rural Watersheds

November 1, 1972

Time	Flow	S.S. (mg/l)	BOD (mg/l)	S.S. (lb/day)	BOD (lb/day)	Coliforms Total Organisms/ml	Coliforms Fecal Organisms/ml
3:15 AM	.220	13.0	2.66	23.833	4.877		
3:45 AM	.500	10.5	2.71	43.750	11.292	930	930
4:15 AM	1.130	14.3	2.75	134.66	25.896		
4:45 AM	1.210	23.0	2.88	231.90	29.040		
5:15 AM	.820	30.8	3.23	210.500	22.071	9,300	9,300
5:45 AM	.590	34.5	3.63	169.600	17.848		
6:15 AM	.780	32.6	3.26	211.900	21.190	4,300	4,300
6:45 AM	1.380	33.5	2.74	385.200	31.510		
7:15 AM	2.310	33.2	2.71	639.10	52.168		
7:45 AM	2.650	32.5	3.58	717.700	79.058		
8:15 AM	2.820	31.5	4.02	740.200	94.470		
8:45 AM	2.620	30.0	4.00	655.00	87.353		
9:15 AM	2.240	27.2	3.97	507.70	74.107		
9:45 AM	1.930	23.5	4.00	378.00	64.333		
10:15 AM	2.220	20.5	4.04	379.20	74.740		
10:45 AM	2.570	20.20	4.08	432.600	87.380		
11:15 AM	2.000	23.80	4.10	396.70	68.333		
11:45 AM	3.320	30.00	4.18	830.00	115.647		
12:15 PM	6.720	30.00	4.28	1680.00	239.68		
12:45 PM	9.410	31.00	4.41	2430.9	345.82	46,000	4,300
1:15 PM	10.110	39.00	4.30	3285.8	362.28		
1:45 PM	10.770	52.50	4.15	4711.90	372.460		
2:15 PM	11.000	29.00	4.10	2658.30	375.830		
2:45 PM	10.300	18.50	4.00	1590.00	344.00		
3:15 PM	10.410						

Table 34, Continued

3:45 PM	10.150
4:15 PM	9.500
4:45 PM	8.140
5:15 PM	7.380
5:45 PM	8.180
6:15 PM	8.880
6:45 PM	7.950
7:15 PM	6.000

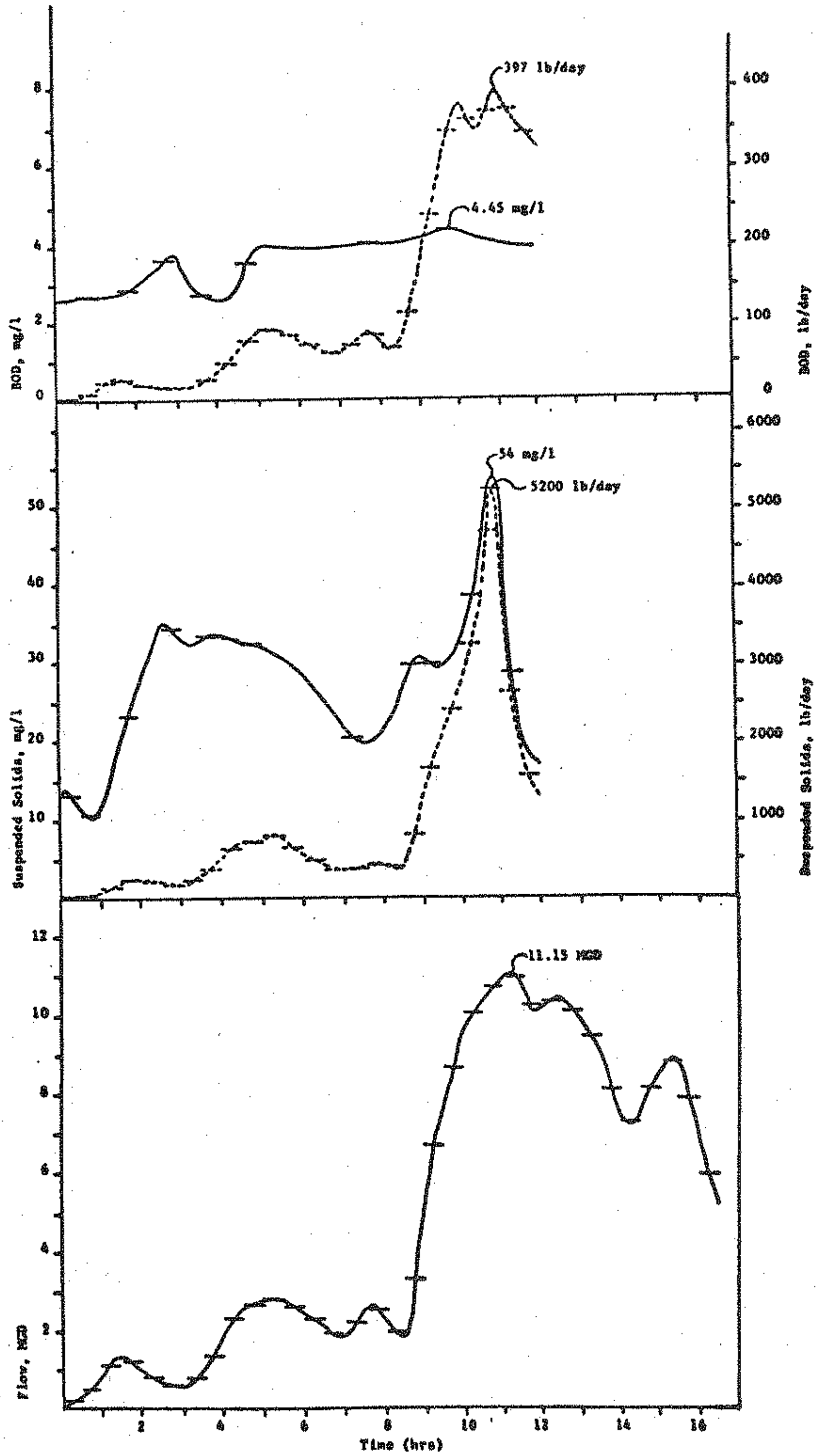

Figure 17. Variation in Flow, BOD, and Suspended Solids During the Storm of Nov. 1, 1972 at the Semi-Urban/Rural Sampling Station.

as peak flow and peak concentration and reached 5200 lb/day (See Table 35). An important feature in the suspended solids concentration graph was that solids were not sufficiently flushed until a relatively high flow was attained.

Table 35

Magnitude and Time of Peak of Flow, BOD, and Suspended Solids for Storm of November 1, 1972 at the Semi-Urban/Rural Sampling Station

Parameter	Time After Initial Flow	Peak	
Flow	11 Hr.	11.15	MGD
BOD	10 Hr.	4.45	mg/1
BOD_1	11 Hr.	397	lb/day
S.S.	11 Hr.	54	mg/1
$S.S._1$	11 Hr.	5200	lb/day

Storm of November 7, 1972

The data for this storm are given in Table 36. The flow in this storm was low, reaching a peak of only 0.89 MGD. As can be seen from Figure 18, the BOD concentration was relatively constant with the peak occurring less than ten minutes after the peak in flow. The concentration of BOD was low regardless of flow and varied only from 2 to 3 mg/1 throughout the entire period of runoff. No "first flush" of BOD concentration was evident.

Table 36

Stormwater Runoff Data from Semi-Urban/Rural Watershed

November 7, 1972

Time	Flow MGD	S.S. mg/1	BOD mg/1	S.S. 1b/day	BOD 1b/day
7:32 AM	.060	13.0	3.00	6.5	1.5
8:02 AM	.640	28.0	3.25	149.3	17.33
8:32 AM	.860	49.0	3.25	351.2	23.29
9:02 AM	.440	51.0	3.15	187.0	11.55
9:32 AM	.186	23.0	3.00	35.65	4.65
10:02 AM	.140	9.0	2.85	10.50	3.32
10:32 AM	.140	14.0	2.65	16.33	3.09
11:02 AM	.155	5.4	2.58	6.96	3.32
11:32 AM	.160	10.5	2.46	14.00	3.28
12:02 PM	.164	7.5	2.32	10.25	3.17

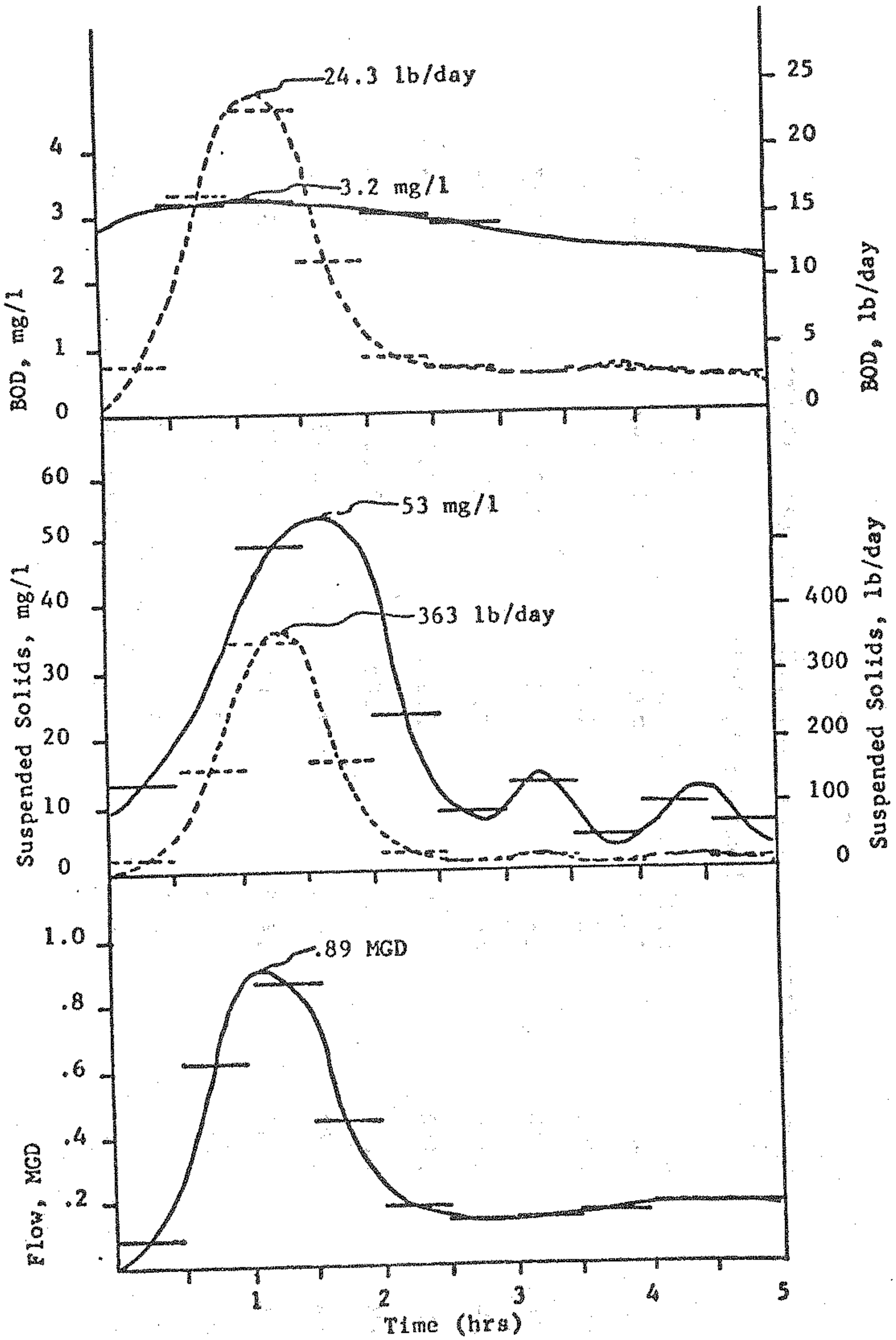

Figure 18. Variation of Flow, BOD and Suspended Solids During the Storm of Nov. 7, 1972 at the Semi-Urban/Rural Sampling Station.

The suspended solids concentration varied directly with flow. The peak occurred about 45 minutes after peak flow but followed the same general pattern as the flow. No "first flush" of solids was evident. The pollutographs for BOD and suspended solids were also directly effected by the flow hydrograph. Peak values for flow, concentration, and mass emission are given in Table 37.

Table 37

Magnitude and Time of Peak of Flow, BOD and Suspended Solids for Storm of November 7, 1972 at the Semi-Urban/Rural Sampling Station

Parameter	Time After Initial Flow	Peak
Flow	1 Hr.	.89 MGD
BOD	1.2 Hr.	3.30 mg/1
BOD	1.2 Hr.	24.30 lb/day
S.S.	1.75 Hr.	53 mg/1
S.S.	1.50 Hr.	363 lb/day

Storm of November 10, 1972

Flow resulting from this storm was extremely low. It was so low, in fact, that no flow was registered at the urban watershed. (See Data in Table 38.) The flow peaked at 0.046 MGD. The BOD concentration remained constant and showed absolutely no sign of peaking or "first flush" (See Figure 19). The highest BOD concentration was found at the end of the sampling period (3.2 mg/1). The suspended solids concentration

Table 38

Stormwater Runoff Data for Semi-Urban/Rural Watershed

November 10, 1972

Time	Flow MGD	S.S. (mg/1)	BOD (mg/1)	S.S. (1b/day)	BOD (1b/day)
4:42 PM	.0145	2.50	2.73	.302	.330
5:12 PM	.0443	2.44	2.58	.901	.952
5:42 PM	.0454	2.50	2.35	.946	.889
6:12 PM	.0382	5.50	2.16	1.750	.688
6:42 PM	.0280	2.50	2.03	.583	.474
7:12 PM	.0180	1.92	2.17	.288	.326
7:42 PM	.0120	1.68	2.50	.168	.250
8:12 PM	.0086	1.48	2.96	.106	.212

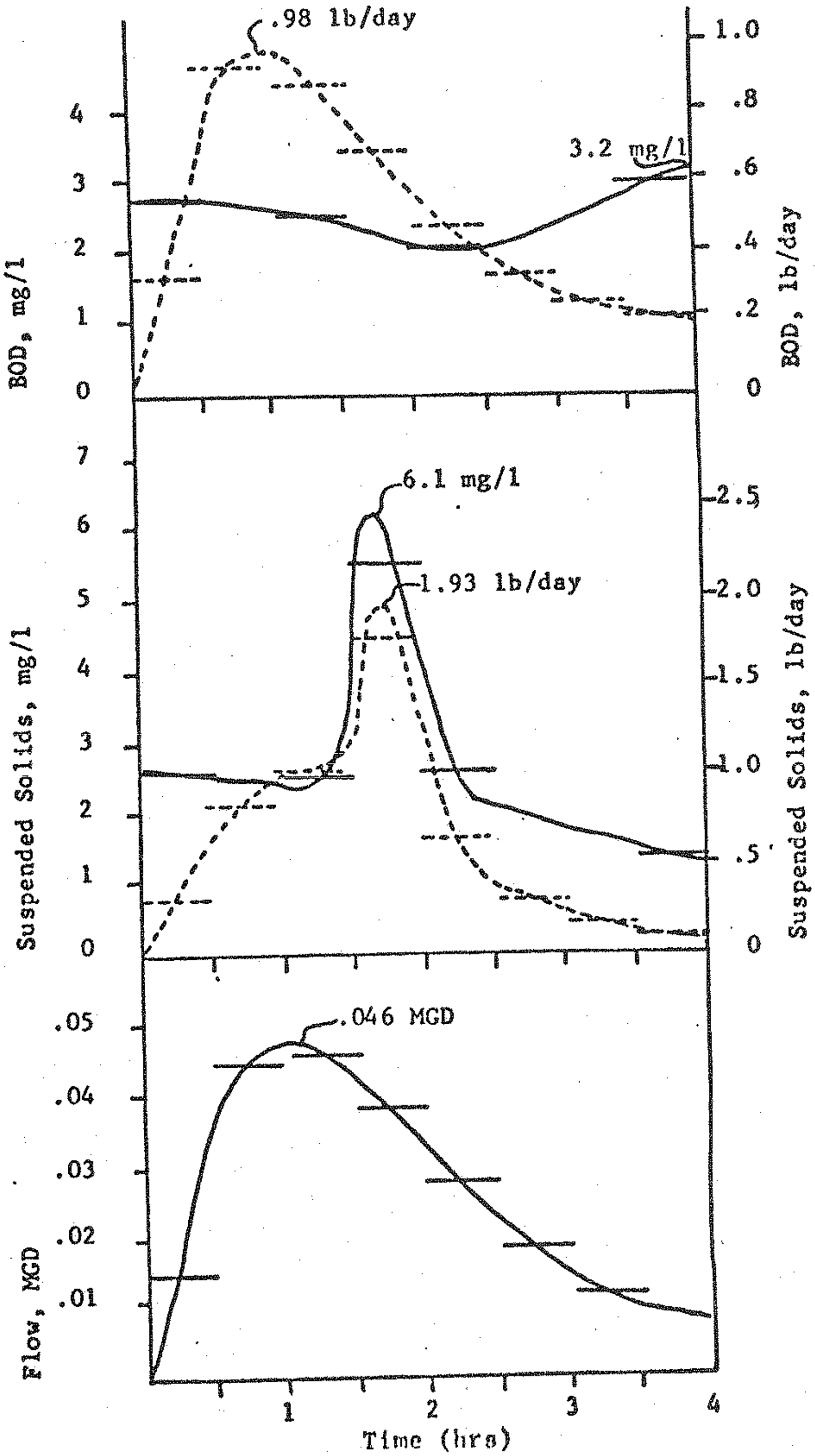

Figure 19. Variation in Flow, BOD, and Suspended Solids for the Storm of Nov. 10, 1972 at the Semi-Urban/Rural Sampling Station.

was extremely low and there was no evidence of "first flushing". The suspended solids concentration peaked about forty-five minutes after peak flow at a value of 6.1 mg/l (See Table 39). The pollutograph of BOD peaked exactly with flow at 0.98 lb/day. The pollutograph of suspended solids peaked with peak concentration at 19.3 lb/day.

Table 39

Magnitude and Time of Peak of Flow, BOD,
Suspended Solids for Storm of November 10, 1972
at Semi-Urban/Rural Sampling Stations

Parameter	Time After Initial Flow	Peak
Flow	1 Hr.	.046 MGD
BOD	4 Hr.	3.2 mg/l
BOD	1 Hr.	.98 lb/day
S.S.	1.75 Hr.	6.1 mg/l
S.S.	1.75 Hr.	19.3 lb/day

Storm of November 13, 1972

The data for this storm is given in Table 40. The flow hydrograph is characterized by two peaks (See Figure 20). The first peak occurred three hours after the start of runoff and reached about 8.6 MGD. The second peak occurred about ten hours after the start of flow and reached 20.3 MGD.

The concentration of BOD peaked one hour after the first peak in flow. The concentration of BOD reached 6.6 mg/l.

Table 40

Stormwater Runoff Data for Semi-Urban/Rural Watershed

Swine Farm

November 13, 1972

Time	MGD Flow	mg/l S.S.	mg/l BOD	lb/day S.S.	lb/day BOD
10:12 AM	1.47	107	5.45	1,310.8	66.8
10:42 AM	3.10	164	5.79	4,236.7	149.6
11:12 AM	5.56	58	4.53	2,687.3	209.9
11:42 AM	7.80	137	5.08	8,905.0	330.2
12:12 PM	7.70	64	5.57	4,106.7	357.4
12:42 PM	6.45	81	6.12	4,353.8	329.0
1:12 PM	5.50	56	6.45	2,566.7	295.6
1:42 PM	4.93	65.3	6.30	2,682.7	258.8
2:12 PM	5.18	34.0	5.75	1,467.7	248.2
2:42 PM	5.80	51.0	5.36	2,465.0	259.1
3:12 PM	4.70	53	5.10	2,340.0	199.7
3:42 PM	4.50	54	4.80	2,250.0	180.0
4:12 PM	5.30	54	4.50	2,670	198.6
4:42 PM	7.40	54	4.30	3,690	265.0
5:12 PM	10.80	54	4.05	5,400	364.2
5:42 PM	15.18	58	3.83	7,337	484.5
6:12 PM	19.00	54.7	3.74	8,661	628.6
6:42 PM	20.40	72.5	3.97	12,324	674.9
7:12 PM	19.95	66.0	4.22	10,972	701.6
7:42 PM	19.88	76.0	4.53	12,591	750.5
8:12 PM	19.02	64.0	4.78	10,144	757.6
8.42 PM	17.31	57.0	5.06	8,222	730.0
9:12 PM	14.72	51.4	5.14	6,305	630.5
9:42	11.70	46.0	4.88	4,485	475.8

Table 40, Continued

10:12 PM	11.02
10:42 PM	10.37
11:12 PM	8.17
11:42 PM	6.52
12:12 AM	5.85
12:42 AM	5.20
1:12 AM	
1:42 AM	

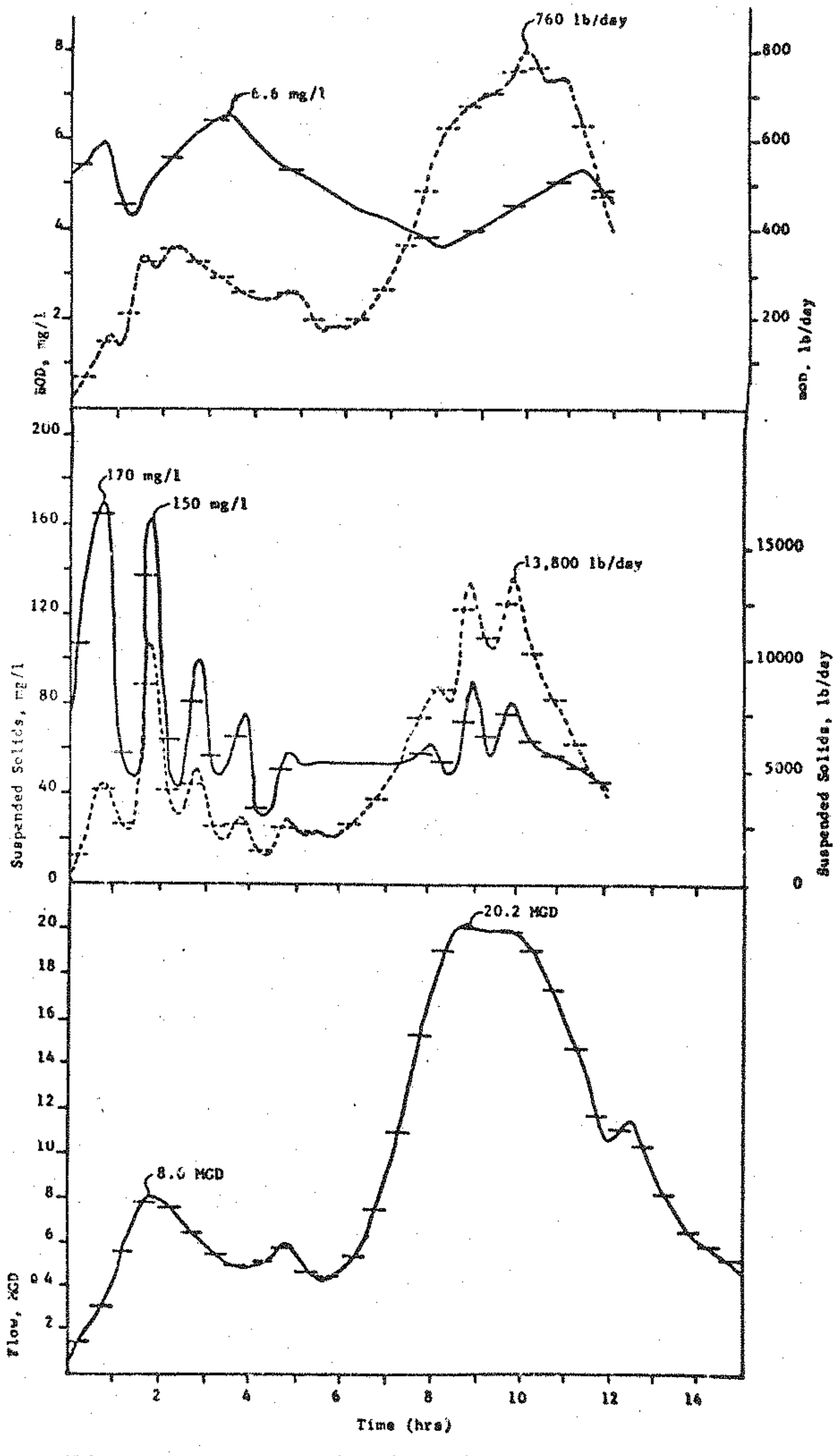

Figure 20. Variation in Flow, BOD, and Suspended Solids for the Storm of Nov. 13, 1972 at the Semi-Urban Rural Sampling Station.

The BOD concentration remained relatively constant (3 - 7 mg/1). A first flush of BOD was not evident. The BOD peaked again with peak flow but was lower than the first peak.

Suspended solids concentration peaked one hour prior to the first peak in flow and again exactly at the first peak flow (170 mg/1 and 150 mg/1, respectively).

After this flush of solids at the first peak in flow, solids decreased dramatically and remained constant throughout the remainder of the storm, even at peak flow. This reinforces the belief that once the flow reaches a certain level, solids will be sufficiently flushed so as to remain constant.

The pounds per day of BOD peaked one hour after peak flow and the shape of the pollutograph is highly dependent on the flow hydrograph. The maximum pounds per day of BOD was 760 lb/day. The pollutograph of suspended solids followed the shape of the S.S. concentration curve. Peaks in concentration that occurred with the first peak in flow dramatically effect the shape of the pollutograph. However, because of the massive flow, the peak in pounds per day occurs one hour after peak flow and reached 13,800 lb/day. Table 41 summarizes the peak values found in this storm.

Comparison of Quality of Runoff from the Test Watersheds

The flow hydrographs for the two types of watersheds (urban and semi-urban/rural) have very similar shapes for

Table 41

Magnitude and Time of Peak of Flow, BOD, Suspended Solids for the Storm of November 13, 1972 at the Semi-Urban/Rural Sampling Station

Parameter	Time After Initial Flow	Peak
Flow (Secondary)	2 Hours	8.6 MGD
Flow (Primary)	8 Hours	20.2 MGD
BOD	3 Hours	6.6 mg/l
BOD	11.5 Hours	5.2 mg/l
BOD	10 Hours	760 lb/day
S.S.	1 Hours	170 mg/l
S.S.	2 Hours	150 mg/l
S.S.	11 Hours	13,800 lb/day

the November 1 and November 13 storms. The time and magnitude of peaks vary but the pattern of the storm runoff is quite similar. For this reason the pollutographs for the two types of watersheds are also similar due to the relationship between flow and mass emissions pounds per day.

In order to compare the two watersheds, it was necessary to derive a useful factor which could reduce the pollutant values to a common scale. This was done by considering the effect of size of the watershed and amount of runoff on the peak pounds per day of pollutants produced. The use of the units of pounds of pollutant per day per acre reduces the pollutants to an equal basis with regard to size of the watershed. By next considering the effect of flow on the poundage or by dividing the pounds per acre per day by MGD one has, in effect, reduced the values to concentration of pollutants generated by storm flow per acre of watershed. Table 42 compares the semi-urban/rural and urban watershed for all storms. The data shows that the concentration of pollutants resulting from the runoff from one acre of urban watershed is much greater than that from the semi-urban/rural watershed. Another interesting aspect of the data is that the values for the parameters are relatively constant for all storms for a given watershed. The ratio of BOD to suspended solids is relatively constant also.

The suspended solids concentrations at both stations varied significantly with flow. At the urban watershed a

Table 42

Comparison of the Two Test Watersheds Peak BOD and S.S. in Terms of Lb/Day/Acre-MGD for All Storms

Date (Time)	Semi-Urban/Rural BOD/S.S.	Urban BOD/S.S.
Oct. 27, 1972		8.22/23.08
Oct. 31, 1972		5.48/18.10
Nov. 1, 1972	.122/1.597	2.11/13.37
Nov. 7, 1972	.094/1.397	
Nov. 10, 1972	.073/ .1437	
Nov. 13, 1972 (8A-4P)	.135/4.301	7.18/23.58
Nov. 13, 1972 (4P-11P)	.136/2.340	2.24/ 7.11

"first flush" of solids occurred with initial runoff. The semi-urban/rural watershed did not seem to have a "first flush". Both watersheds seemed highly dependent on flow at low flow. In one storm at the urban watershed in which the flow was moderately high, the concentration of suspended solids increased with flow but after peak flow the concentration remained constant regardless of flow. This suggests that there may exist some minimum flow level that is required to flush solids completely from the basin after which the solids concentration remained constant.

The BOD concentration at the semi-urban/rural watershed was relatively constant and had little or no relationship to flow. The maximum range of BOD for a given storm was from 3.2 mg/l to 6.6 mg/l. There was no first flush effect and little or no peaking of concentration.

The BOD concentration at the urban watershed often exhibited "first flushing" though it was not as evident as suspended solids concentration. The concentration of BOD varied with flow but again not as dramatically as suspended solids. In fact, after a significant flow occurs, the BOD remains relatively constant. This flow was less than that for suspended solids to remain constant.

Discussion of Sampling Methodology

Introduction

Before further studies are done on the watersheds, an analysis of the sampling procedure needs to be performed. This section deals with the relative effectiveness of the sampling procedures and suggests how certain modifications in this procedure would effect the results obtained.

Size of Sample

In this study, approximately one liter of sample was collected in a half hour period at the semi-urban/rural watershed and varying amounts of sample ranging from 500 milliliter to a liter was collected in the same time period at the urban watershed. The reason for the varying amounts of sample at the urban sampling station was due to head differential in the storm sewer and its effect of the pumping capacity of the sampler. A great deal of experimentation needs to be done in order to increase the volume of sample delivered, if more analysis are to be run on the sample. Still more experimentation needs to be done to assure a constant volume of sample. It was found that at the urban sampling station during low flow conditions the volume of sample was much less than at high flows. This meant that at initial flow and receding flow you would have less sample on which analysis could be run. This did not cause any serious difficulties for two reasons: 1) At initial runoff the concentration of BOD and suspended solids was quite high and not as much sample was required for analysis, and 2) At receding flow BOD and suspended solids concentration were low but relatively constant. Combining this with the fact that the greater portion of the pounds of pollutants had passed it was evident that fewer samples needed to be analyzed. This allowed the compositing of several small samples to obtain an average value for the concentration of pollutants over a time period greater than a half-hour.

The size of sample must be increased from one liter to about one and a half liters in order to run analysis on samples with low concentration. For example, if a sample has a BOD of 6 mg/l or less, one needs to run a full strength analysis. Assuming one initial dissolved oxygen and three final dissolved oxygen, one requires 1200 mls of sample.

Combining this with the volume required to run standard solids and any other analysis, a volume of at least 1500 ml is needed. The size of sample can be increased by decreasing the frequency and combining two samples collected using the original frequency or by experimenting with the various operations of the sampling equipment itself.

Frequency of Sampling

The most important parameter, insofar as the impact of a pollutant on a receiving stream is concerned, is the pounds of that pollutant which must be assimilated by the stream. Therefore, it seems logical that in order to determine how frequent samples should be taken, it first must be determined how the frequency of sampling effects the shape of the pollutograph or how it effects the pounds of a given pollutant. If there is indeed some maximum level of pounds that a stream can handle then the concern should be with those values which exceed this level. For this reason the main concern should be with peak mass emission rates and the effect of frequency on these peaks.

A series of tables and graphs were constructed with the purpose of outlining the effects of the following conditions: 1) The effect of compositing one and two hour concentrations on the shape of the pollutograph using half hour mean flows; 2) the effect of using one hour and two hour mean flow values, combined with the one and two hour mean sample concentrations on the shape of the pollutograph. This analysis would show the effect of concentration and flow on the pollutograph.

Tables 43 - 50 and Figures 21 - 28 present the data when analyzed according to the conditions listed above. Four stormwater runoff events were chosen for comparison. They were the storms of November 1 and November 13 at both the urban and semi-urban/rural watersheds. It can be seen from the graphs that the general shape of the curves were not effected except at peak values. The peak values decreased as the frequency decreased; i.e., the peak values decreased as the sampling interval increased. Table 51 shows the effect of the type of conditions on the magnitude and time of peak. Table 52 shows the percent deviation from the original value for each situation. It can be seen that, generally, increasing the sampling interval increases the percent deviation as does increasing the mean flow interval. It can also be seen that the flow has a greater effect on the shape of the pollutograph than does the concentration.

The sampling frequency greatly effects the amount of labor required for a given storm. Therefore, in determining the sampling frequency, a compromise must be made between accuracy and available sampling time.

Sampling frequency significantly effects the shape of the quality graph. If an investigator is interested in "first flush" phenomena or the maximum values of concentration

Table 43

The Effect of One and Two Hour Sampling Intervals on the Magnitude of Mass Emissions when a Half-Hour Mean Flow Interval is Used for the November 1, 1972 Storm at the Urban Sampling Station

		1 Hr Composite				2 Hr Composite			
		mg/l		lb/day		mg/l		lb/day	
Time	MGD	S.S.	BOD	S.S.	BOD	S.S.	BOD	S.S.	BOD
4:00 AM	.040	17.5	10.4	5.83	3.47			5.92	3.24
4:30 AM	.105			15.31	9.10	17.75	9.73	15.53	8.51
5:00 AM	.157	18.0	9.06	23.55	11.85			23.22	12.73
5:30 AM	.182			27.30	13.74			26.92	14.76
6:00 AM	.168	21.5	9.46	30.10	13.24			24.85	11.37
6:30 AM	.145			25.98	11.43	17.75	8.12	21.45	9.81
7:00 AM	.226	14.0	6.79	26.37	12.79			33.43	15.29
7:30 AM	.064			7.47	3.62			9.47	4.33
8:00 AM	.050	21.0	6.38	8.75	2.66			6.72	2.55
8:30 AM	.078			13.65	4.15	16.12	6.12	10.48	3.98
9:00 AM	.154	11.25	5.87	14.44	7.53			20.69	7.85
9:30 AM	.083			7.78	4.06			11.15	4.23
10:00 AM	.045	9.00	4.40	3.38	1.65			3.16	1.72

Table 43, Continued

10:30 AM	.246			18.45	9.02	8.42	4.59	17.26	9.41
11:00 AM	.554	7.85	4.78	36.24	22.07			38.87	21.19
11:30 AM	.601			39.32	23.94			42.17	22.99
12:00 PM	.337	36.5	6.49	102.50	18.23			102.50	19.46
12:30 PM	.439			133.53	23.74	36.5	6.93	133.53	25.35
1:00 PM	.504	36.5	7.37	153.30	30.95			153.30	29.11
1:30 PM	.244			74.22	14.99			74.22	14.09

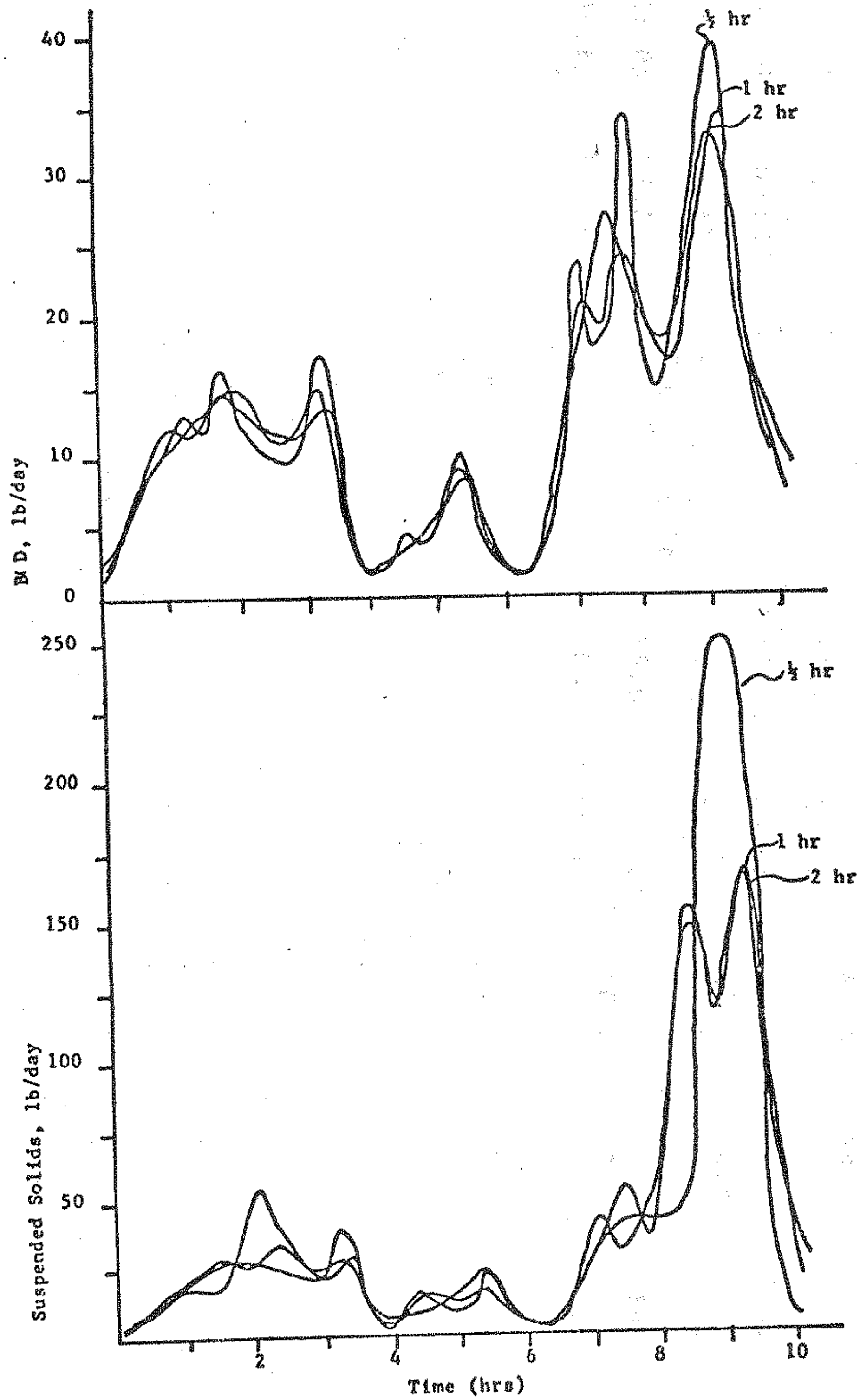

Figure 21. BOD and Suspended Solids Mass Emissions Pollutographs for 1/2, 1, and 2 Hour Sampling Intervals When a 1/2 Hour Flow Interval is Used for the Storm of Nov. 1, 1972 at the Urban Sampling Station.

Table 44

The Effect of One and Two Hour Sampling Intervals on the Magnitude of Mass Emissions when a Half-Hour Mean Flow Interval is Used for the November 1, 1972 Storm at the Semi-Urban/Rural Sampling Station

Time	Flow MGD	1 Hr Composite mg/1 S.S.	1 Hr Composite mg/1 BOD	1 Hr Composite lb/day S.S.	1 Hr Composite lb/day BOD	2 Hr Composite mg/1 S.S.	2 Hr Composite mg/1 BOD	2 Hr Composite lb/day S.S.	2 Hr Composite lb/day BOD
3:15 AM	.220	11.75	2.68	21.54	4.91	15.21	2.75	27.88	5.04
3:45 AM	.500			49.00	11.17			63.88	11.46
4:15 AM	1.130	18.67	2.82	175.80	26.55			143.20	25.90
4:45 AM	1.210			188.26	28.43			153.4	27.72
5:15 AM	.820	32.65	3.43	223.10	23.44			213.9	22.00
5:45 AM	.590			160.55	16.86	31.3	3.22	153.9	15.83
6:15 AM	.780	30.05	3.00	195.30	19.50			203.4	20.93
6:45 AM	1.380			345.6	34.50			360.0	37.03
7:15 AM	2.310	32.85	3.14	632.4	60.44			612.0	68.72
7:45 AM	2.650			725.4	69.34	31.80	3.57	702.2	78.84
8:15 AM	2.820	30.75	4.01	722.6	94.23			747.3	83.89
8:45 AM	2.620			671.4	87.55			694.3	77.94

Table 44, Continued

9:15 AM	2.240	25.35	3.98	473.2	74.29	22.85	4.02	426.5	75.03
9:45 AM	1.930			407.7	63.68			367.5	64.32
10:15 AM	2.220	20.35	4.06	376.5	75.11			422.7	74.37
10:45 AM	2.570			435.8	86.95			489.4	86.09
11:15 AM	2.000	26.90	4.19	448.3	69.83	28.70	4.27	478.3	71.00
11:45 AM	3.320			744.0	115.90			794.0	117.90
12:15 PM	6.720	30.50	4.34	1708.0	243.0			1607.0	238.60
12:45 PM	9.410			2392.0	340.3			2250.0	334.00
1:15 PM	10.110	45.75	4.22	3851.0	355.5	34.75	4.14	2925.0	348.80
1:45 PM	10.770			4106.0	378.7			3119.0	371.60
2:15 PM	11.000	23.75	4.05	2177.0	371.2			3185.0	379.50
2:45 PM	10.300			2039.0	347.6			2983.0	355.30

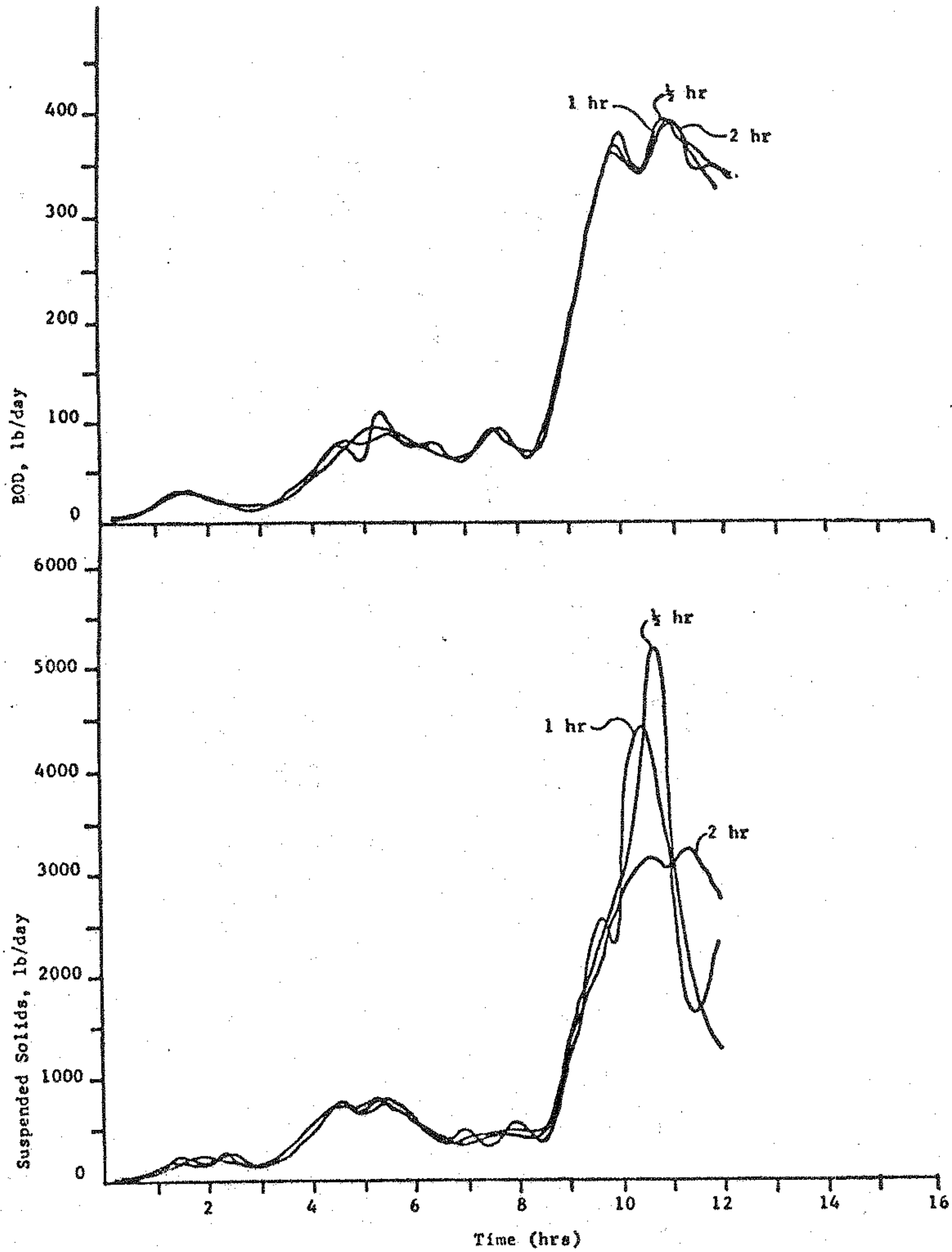

Figure 22. BOD and Suspended Solids Mass Emissions Pollutograph for 1/2, 1, and 2 Hour Sampling Intervals When a 1/2 Hour Flow Interval is Used for the Storm of Nov. 1, 1972 at the Semi-Urban/Rural Sampling Station.

Table 45

The Effect of One and Two Hour Sampling Intervals on the Magnitude of Mass Emissions When Corresponding Mean Flow Intervals are Used for the November 1, 1972 Storm at the Urban Sampling Station

	1 Hr Composite					2 Hr Composite				
Time	Flow MGD	S.S. mg/1	BOD mg/1	S.S. 1b/day	BOD 1b/day	Flow MGD	S.S. mg/1	BOD mg/1	S.S. 1b/day	BOD 1b/day
4:00	.0725	17.5	10.4	10.57	6.28					
						.121	17.75	9.73	17.90	9.81
5:00	.1695	18.0	9.06	25.42	12.80					
6:00	.1565	26.5	9.46	34.56	12.34					
						.15075	20.25	8.12	25.45	10.20
7:00	.1450	14.0	6.79	16.92	8.20					
8:00	.0640	21.00	6.38	11.20	3.40					
						.09125	16.125	6.12	12.25	4.65
9:00	.1185	11.25	5.87	11.11	5.80					
10:00	.1455	9.00	4.40	10.91	5.33					
						.3615	8.425	4.59	25.38	13.83
11:00	.5775	7.85	4.78	37.78	23.00					
12:00	.3880	36.5	6.49	118.01	20.98					
						.3810	36.5	6.93	115.88	22.00
1:00	.3740	36.5	7.37	114.06	23.03					

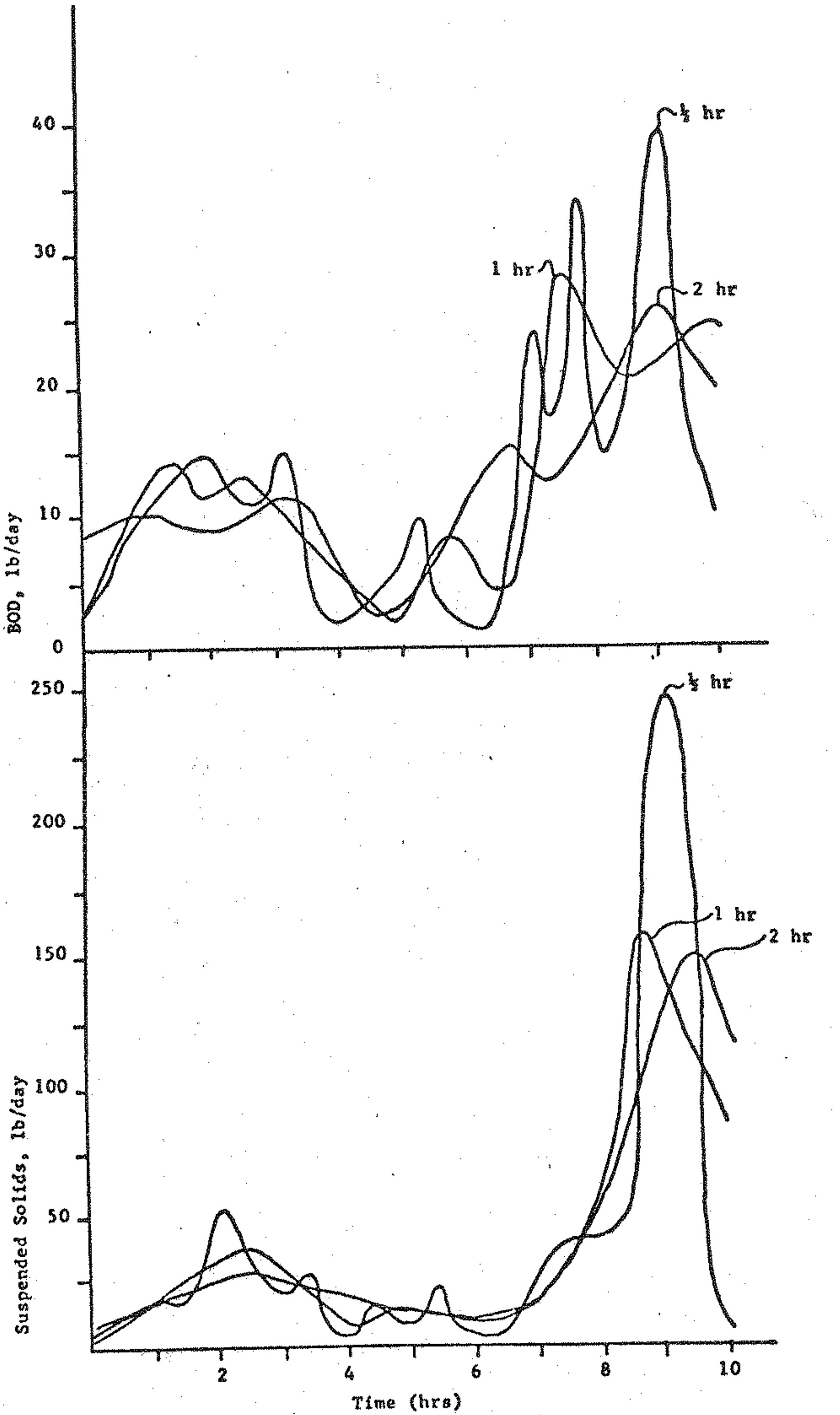

Figure 23. BOD, and Suspended Solids Mass Emission Pollutographs for 1/2, 1, and 2 Hour Sampling Intervals when Corresponding Flow Intervals are Used for the Storm of Nov. 1, 1972 at the Urban Sampling Station.

Table 46

The Effect of One and Two Hour Sampling Intervals on the Magnitude of Mass Emissions When Corresponding Mean Flow Intervals are Used for the November 1, 1972 at the Semi-Urban/Rural Sampling Station

		1 Hr Composite					2 Hr Composite			
Time	Flow MGD	S.S. mg/1	BOD mg/1	S.S. 1b/day	BOD 1b/day	Flow MGD	S.S. mg/1	BOD mg/1	S.S. 1b/day	BOD 1b/day
3:15	.360	11.75	2.68	35.25	8.04					
						.765	15.21	2.75	96.96	17.53
4:15	1.170	18.67	2.82	182.03	27.49					
5:15	.705	32.65	3.43	191.82	20.15					
						.8925	31.30	3.22	232.8	23.95
6:15	1.080	30.05	3.00	270.45	27.00					
7:15	2.480	32.85	3.14	678.89	64.89					
						2.600	31.80	3.57	688.99	77.35
8:15	2.720	30.75	4.01	595.99	90.89					
9:15	2.085	25.35	3.98	440.45	69.15					
						2.240	22.85	4.02	426.5	75.04
10:15	2.395	20.35	4.06	406.15	81.03					
11:15	1.660	26.90	4.19	372.11	57.96					
						4.8625	28.70	4.26	1162.9	172.6
12:15	8.065	30.50	4.34	2049.84	291.68					
1:15	10.44	45.75	4.22	3980.23	367.14					
						10.545	34.75	4.14	3053.6	363.8
2:15	10.65	23.75	4.05	2107.80	359.44					

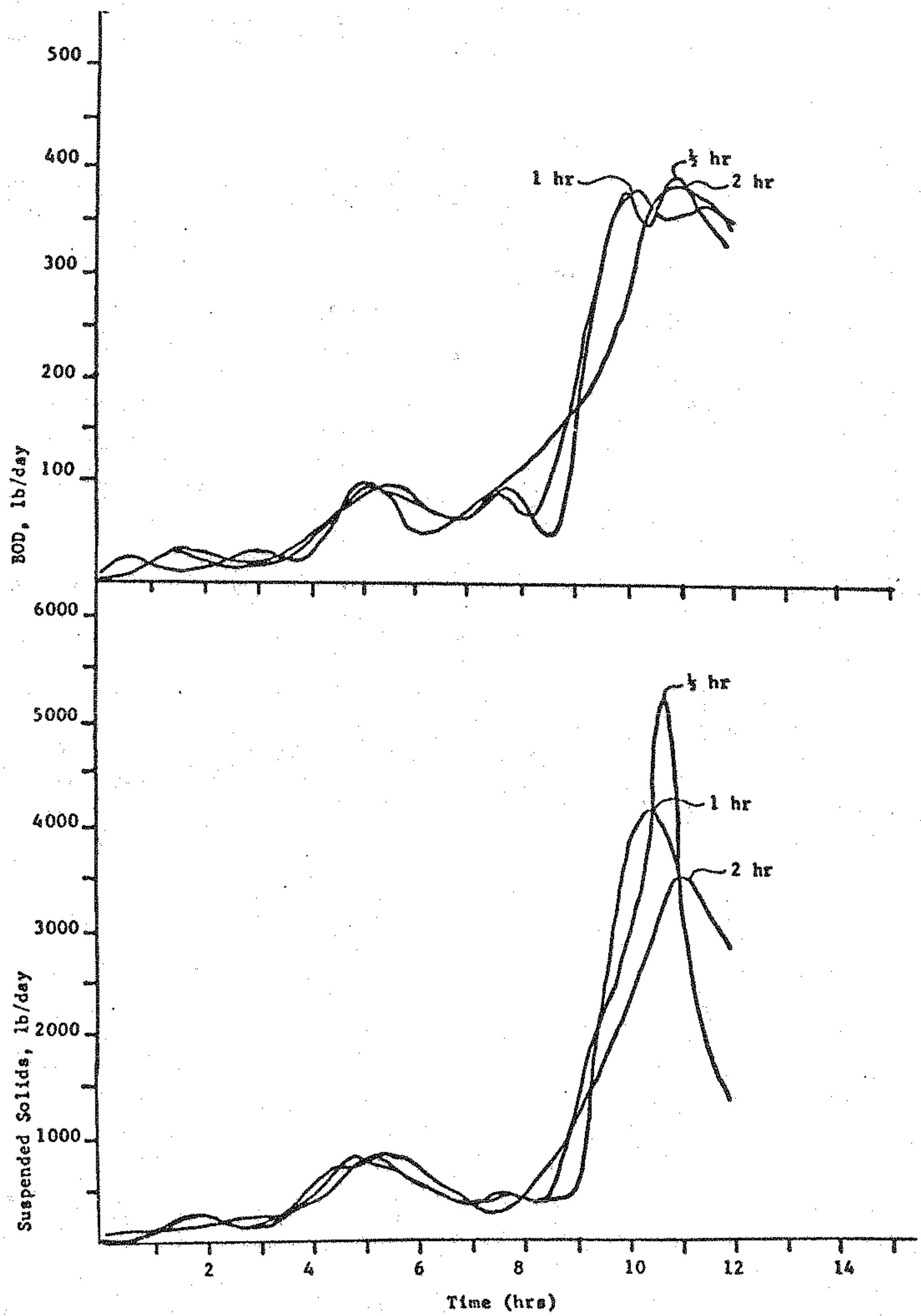

Figure 24. BOD and Suspended Solids Mass Emissions Pollutograph for 1/2, 1, and 2 Hour Sampling Intervals are used for the Storm of Nov. 1, 1972 at the Semi-Urban/Rural Sampling Station.

Table 47

The Effect of One and Two Hour Sampling Intervals on the Magnitude of Mass Emissions when a Half-Hour Mean Flow Interval is Used for the November 13, 1972 Storm at the Urban Sampling Station

		1 Hr Composite				2 Hr Composite			
		mg/1		lb/day		mg/1		lb/day	
Time	Flow	S.S.	BOD	S.S.	BOD	S.S.	BOD	S.S.	BOD
8:08 AM	.004	176	17.74	5.87	.59	142.5	27.65	4.75	.922
8:38 AM	.012			17.60	1.77			14.25	2.765
9:08 AM	.025	109	37.56	22.70	7.825			29.69	5.760
9:38 AM	.037			33.61	11.581			43.94	8.53
10:08 AM	.072	54.25	24.15	32.55	14.49	60.62	22.45	36.37	13.47
10:38 AM	.132			59.68	26.56			66.68	24.70
11:08 AM	.152	67.00	20.75	84.87	26.28			76.79	28.44
11:38 AM	.087			48.58	15.04			43.95	16.28
12:08 PM	.031	42.00	23.65	10.85	6.11	33.75	24.92	8.72	6.44
12:38 PM	.011			3.85	2.17			3.09	2.28
1:08 PM	.021	25.5	26.2	4.46	4.58			5.91	4.36
1:38 PM	.033			7.01	7.20			9.28	6.85

Table 47, Continued

2:08 AM	.039	28.0	21.25	9.10	6.91			8.78	7.38
2:38 AM	.043			10.03	7.61	27.0	22.72	9.68	8.14
3:08 AM	.039	26.0	24.18	8.45	7.86			8.78	7.38
3:38 AM	.059			12.78	11.89			13.28	10.17
4:08 AM	.134	33.5	9.54	37.41	10.65			33.22	9.73
4:38 AM	.132			36.85	10.49	29.75	8.71	32.72	9.58
5:08 AM	.139	26.0	8.40	30.12	9.73			34.46	10.09
5:38 AM	.271			58.72	18.97			67.19	19.67
6:08 AM	.436	26.0	8.42	94.47	30.59			98.10	31.21
6:38 AM	.331			71.72	23.23	27.0	8.59	74.48	23.69
7:08 AM	.219	28.0	8.76	51.10	15.99			94.28	15.68
7:38 AM	.279			65.10	20.37			62.78	19.97
8:08 AM	.187	18.5	9.04	28.83	14.09			32.34	13.92
8:38 AM	.121			18.65	9.12	20.75	8.93	20.92	9.00
9:08 AM	.071	23.0	8.82	13.61	5.22			12.28	5.28
9:39 AM	.046			8.82	3.38			7.95	3.42

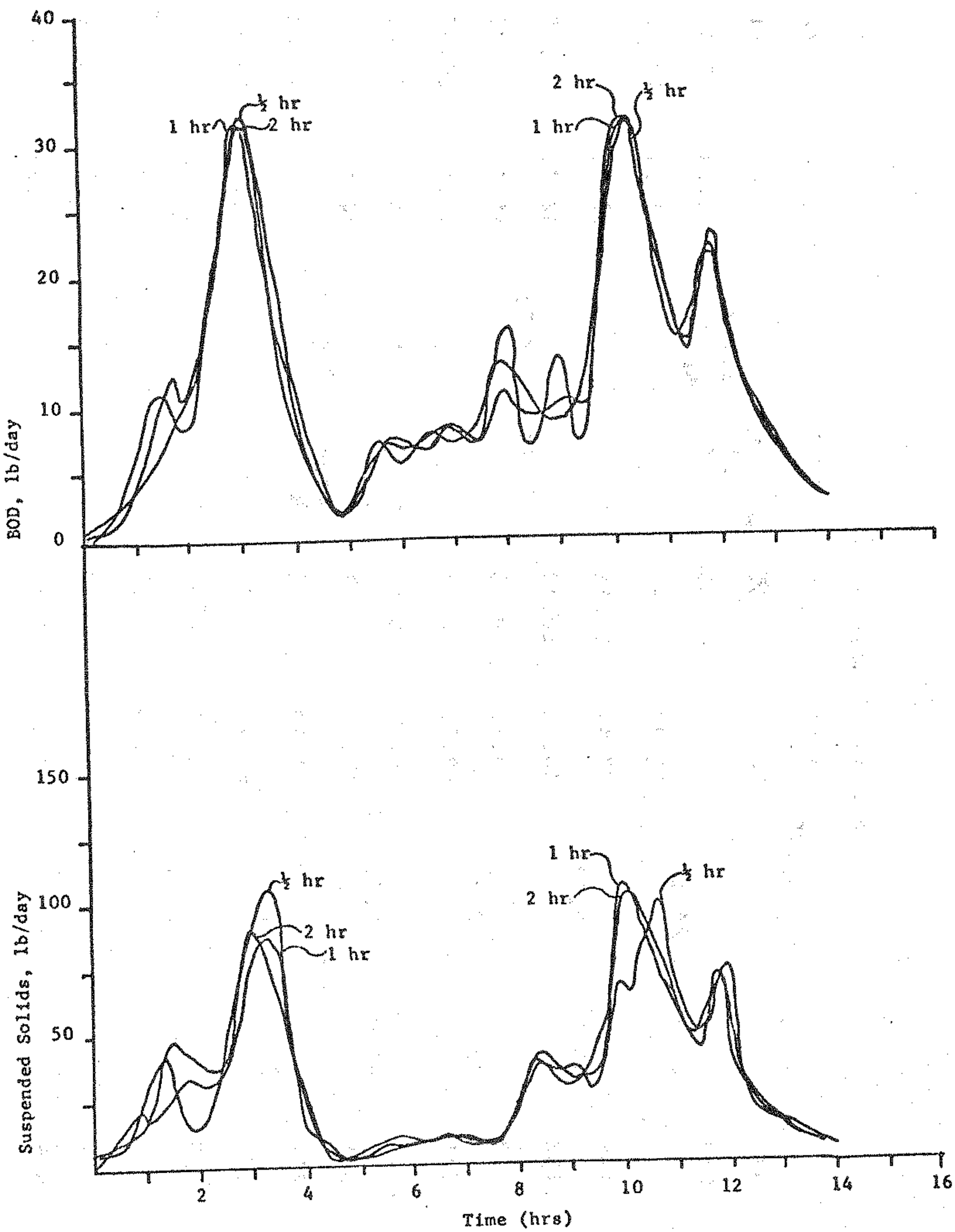

Figure 25. BOD and Suspended Solids Mass Emission Pollutographs for 1/2, 1, and 2 Hour Sampling Intervals When a 1/2 Hour Flow Interval is Used for the Storm of Nov. 13, 1972 at the Urban Sampling Station.

Table 48

The Effect of One and Two Hour Sampling Intervals on the Magnitude of Mass Emissions when a Half-Hour Mean Flow Interval is Used for the November 13, 1972 Storm at the Semi-Urban/Rural Sampling Station

		1 Hr Composite				2 Hr Composite			
		mg/l		lb/day		mg/l		lb/day	
Time	Flow	S.S.	BOD	S.S.	BOD	S.S.	BOD	S.S.	BOD
10:12 AM	1.47	136	5.62	1666	69.9	117	5.21	1433	63.8
10:42 AM	3.10			3513	145.2			3022	134.6
11:12 AM	5.56	98	4.80	4541	222.4			5420	241.4
11:42 AM	7.80			6370	312.0			7605	338.6
12:12 PM	7.70	72	5.84	4620	374.7	66.3	6.11	4254	392.1
12:42 PM	6.45			3870	313.9			3564	328.4
1:12 PM	5.50	60.6	6.38	2777	292.4			3039	280.0
1:42 PM	4.93			2490	262.1			2724	251.0
2:12 PM	5.18	42.5	5.56	1835	240.0	48.25	5.255	2083	226.8
2:42 PM	5.80			2054	268.7			2332	254.0
3:12 AM	4.70	54	4.95	2115	193.9			1890	205.8
3:42 PM	4.50			2025	185.6			1809	197.1

Table 48, Continued

4:12 PM	5.30	54		4.40	2385	194.3			2429	184.2
4:42 PM	7.40				3330	271.3	55.0	4.17	3392	257.1
5:12 PM	10.80	56		3.94	5040	354.6			4950	375.3
5:42 PM	15.18				7084	498.4			6951	527.5
6:12 PM	19.0	63.6	10070		10070	611.2			10577	652.3
6:42 PM	20.40				10812	656.2	66.80	4.12	11356	700.4
7:12 PM	19.95	70.0		4.38	11637	728.2			11105	684.9
7:42 PM	19.88				11597	725.6			11066	682.5
8:12 PM	19.02	60.5		4.92	9589	779.8			8654	786.9
8:42 PM	17.31				8727	709.7	54.6	4.965	7876	716.2
9:12 PM	14.72	48.7		5.01	5974	614.6			6698	609.0
9:42 PM	11.70				4748	488.5			5323	484.1

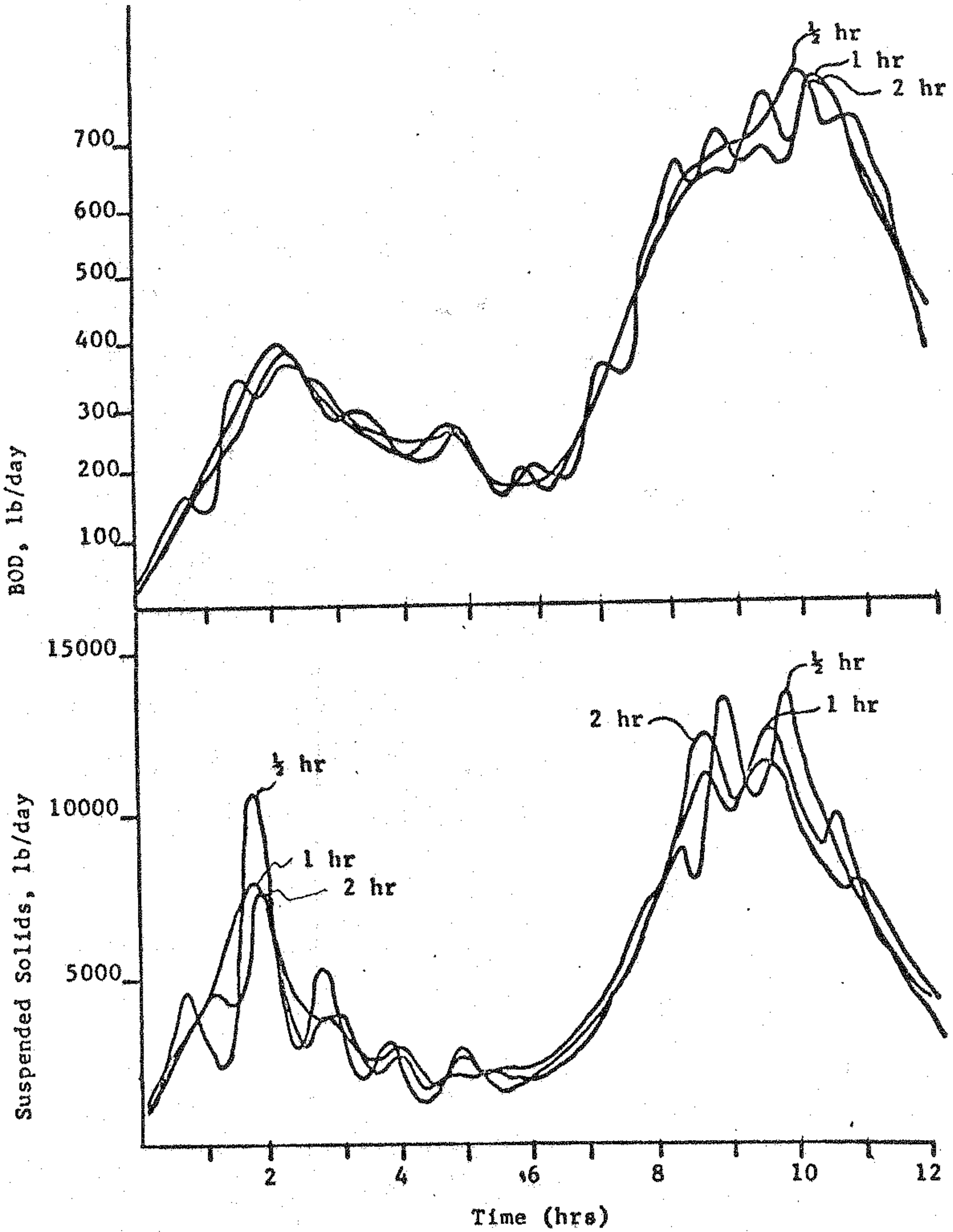

Figure 26. BOD and Suspended Solids Mass Emission Pollutographs for 1/2, 1, and 2 Hour Sampling Intervals When a 1/2 Hour Flow Interval is used for the Storm of Nov. 1, 1972 at the Semi-Urban/Rural Sampling Station.

Table 49

The Effect of One and Two Hour Sampling Intervals on the Magnitude of Mass Emissions When Corresponding Mean Flow Intervals are Used for the November 13, 1972 Storm at the Urban Sampling Station

	1 Hr Composite					2 Hr Composite				
Time	Flow MGD	S.S. mg/l	BOD mg/l	S.S. lb/day	BOD lb/day	Flow MGD	S.S. mg/l	BOD mg/l	S.S. lb/day	BOD lb/day
8:08 AM	.008	176	17.74	11.72	1.18	.0195	142.5	27.65	23.14	4.49
9:08 AM	.031	109	37.56	28.15	9.70	.11075	60.62	22.45	55.97	20.73
10:08 AM	.102	54.25	24.15	46.11	20.52					
11:08 AM	.1195	67	20.75	66.72	20.66	.0240	33.75	24.75	6.75	4.98
12:08 PM	.0210	42	23.65	7.35	4.14					
1:08 PM	.0270	25.5	26.20	5.73	5.89	.045	27.0	22.72	10.12	8.52
2:08 PM	.0410	28	21.25	9.56	7.26					
3:08 PM	.0490	26	24.18	10.62	9.87	.169	29.75	8.71	41.90	12.27
4:08 PM	.1330	33.5	9.54	37.13	10.57					
5:08 PM	.2050	26	8.40	44.42	14.35	.31625	27.00	8.59	71.14	22.63
6:08 PM	.3835	26	8.42	83.09	29.91					
7:08 PM	.2490	28	8.76	58.10	18.18	.10625	20.75	8.93	18.36	7.90
8:08 PM	.1540	18.5	9.04	23.74	11.60					
9:08 PM	.0585	23	8.82	11.21	4.30					

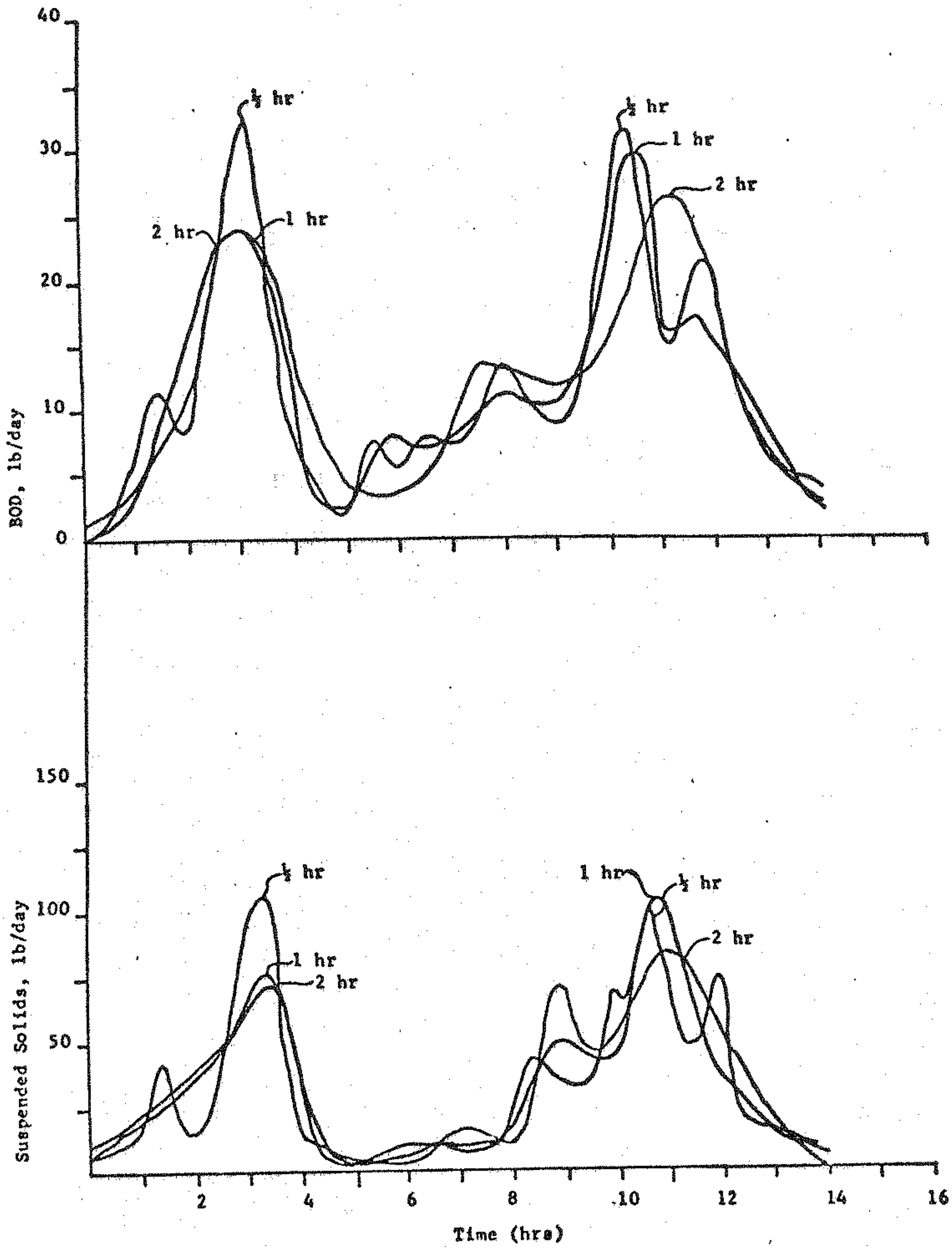

Figure 27. BOD and Suspended Solids Mass Emission Pollutographs for 1/2, 1, and 2 Hour Sampling Intervals when Corresponding Flow Intervals are Used for the Storm of Nov. 13, 1972 at the Urban Sampling Station.

Table 50

The Effect of One and Two Hour Sampling Intervals on the Magnitude of Mass Emissions When Corresponding Mean Flow Intervals are Used for the November 13, 1972 Storm at the Semi-Urban/Rural Sampling Station

Time	Flow MGD	1 Hr Composite S.S. mg/1	BOD mg/1	S.S. lb/day	BOD lb/day	Flow MGD	2 Hr Composite S.S. mg/1	BOD mg/1	S.S. lb/day	BOD lb/day
10:12	2.285	136	5.62	2590	107.0					
						4.4825	117	5.21	4370	194.6
11:12	6.680	98	4.80	5455	267.2					
12:12	7.075	72	5.84	4245	344.3					
						6.145	66.3	6.11	3395	312.9
1:12	5.215	60.6	6.38	2634	277.3					
2:12	5.490	42.5	5.56	1944	254.4					
						5.045	48.25	5.255	2028	220.9
3:12	4.600	54.0	4.95	2070	189.7					
4:12	6.350	54.0	4.40	2857	232.8					
						9.67	55.0	4.17	4432	336.0
5:12	12.990	56.0	3.94	6062	426.5					
6:12	19.700	63.6	3.86	10441	633.7					
						19.8075	66.8	4.12	11026	680.1
7:12	19.915	70.0	4.38	11617	726.9					
8:12	18.65	60.5	4.92	9158	744.8					
						15.6825	54.6	4.965	7.38	649.1
9:12	13.210	48.7	5.01	5361	551.5					

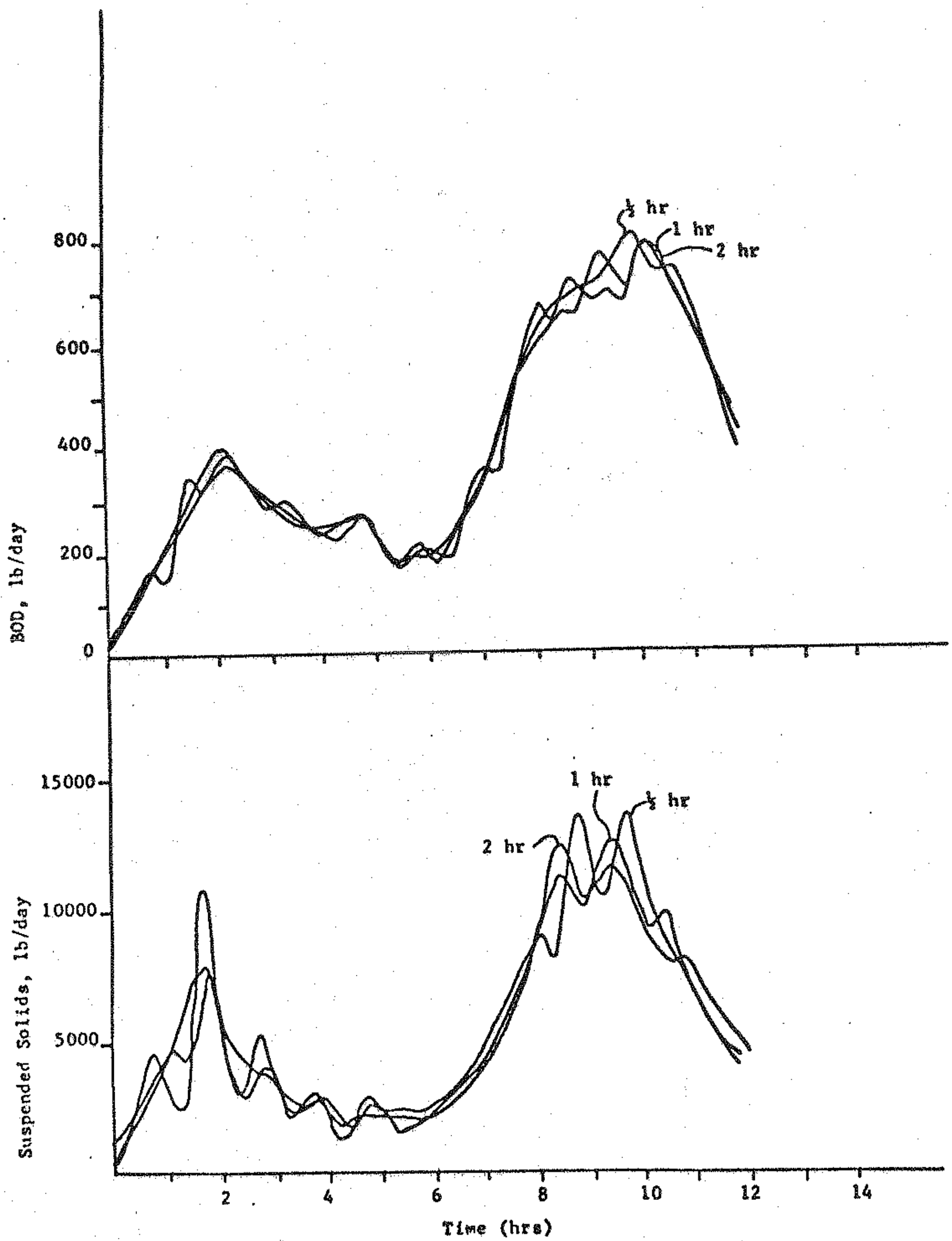

Figure 28. BOD and Suspended Solids Mass Emission Pollutographs for 1/2, 1, and 2 Hour Sampling Intervals When Corresponding Flow Intervals are used for the Storm of Nov. 13, 1972 at the Semi-Urban/Rural Sampling Station.

Table 51

Comparison of Peak Mass Emission Values Resulting from Various Sampling and Flow Intervals for Storms of November 1, and November 13, 1972 at the Two Test Watersheds

		Type of Composite									
		1/2 Hour Sample 1/2 Hour Flow		1 Hour Sample 1/2 Hour Flow		1 Hour Sample 1 Hour Flow		2 Hour Sample 1/2 Hour Flow		2 Hour Sample 2 Hour Flow	
Storm	Parameter	Time of Peak	lb/day	Time of Peak	lb/day	Time of Peak	lb/day	Time of Peak	lb/day	Time of Peak	lb/day
Nov. 1, 1972 Urban Station	S.S.	1:00 AM	250	1:20 AM	166	12:53 AM	158	1:20 AM	166	1:06 AM	150
	BOD	1:08 AM	39.4	1:10 AM	34.5	11:42 PM	28.4	1:02 AM	328	1:54 AM	26.0
Nov. 1, 1972 Semi-Urban/Rural Station	S.S.	2:06 AM	5200	1:45 AM	4450	1:45 AM	4100	2:36 AM	3250	2:21 AM	3500
	BOD	2:15 AM	397	2:15 AM	397	1:30 AM	382	2:18 AM	394	2:15 AM	385
Nov. 13, 1972 Urban Station	S.S.	11.26 AM	106.0	6.08 PM	106.0	6:56 PM	102.0	6:14 PM	102.0	7:08 PM	83.0
	BOD	11:08 AM	32.25	11:08 PM	31.8	6:38 PM	29.6	6:20 PM	32.0	7:20 PM	26.4
Nov. 13, 1972 Semi-Urban/Rural Station	S.S.	8:03 PM	13800	7:51 PM	12800	7:20 PM	13000	6:51 PM	12500	7:24 PM	12600
	BOD	8:20 PM	800	8:27 PM	800	8:51 PM	770	8:30 PM	790	7:18 PM	750

Table 52

Percent Deviation in Peak Mass Emission Values Resulting from Various Sampling and Flow Intervals for Storms of Nov. 1 and Nov. 13, 1972 at the Two Test Watersheds

Type of Composite

Storm	Parameter	1/2 Hour Sample 1/2 Hour Flow lb/day	1 Hour Sample 1/2 Hour Flow lb/day	1 Hour Sample 1/2 Hour Flow %deviation	1 Hour Sample 1 Hour Flow lb/day	1 Hour Sample 1 Hour Flow % deviation	2 Hour Sample 1 Hour Flow lb/day	2 Hour Sample 1 Hour Flow % deviation	2 Hour Sample 2 Hour Flow lb/day	2 Hour Sample 2 Hour Flow % deviation
Nov. 1, 1972 Urban Station	S.S.	250	166	33.6	158	36.8	166	33.6	150	40
	BOD	39.4	34.5	12.3	28.4	27.9	32.8	16.7	26.0	33.9
Nov. 1, 1972 Semi-Urban/Rural Station	S.S.	5200	4450	14.4	4100	21.1	3250	37.4	3500	32.7
	BOD	397	397	0	382	3.8	394	0.8	385	3.5
Nov. 13, 1972 Urban Station	S.S.	106	106	0	102	3.8	102	3.8	38.0	21.6
	BOD	32.25	31.8	1.5	29.6	8.1	32.0	0.7	26.4	18.2
Nov. 13, 1972 Semi-Urban/Rural Station	S.S.	13800	12800	7.3	13000	5.9	12500	9.4	12600	8.6
	BOD	800	800	0	770	3.8	790	1.2	750	6.3

of a given pollutant, he must use a sampling frequency that will sufficiently describe these transient occurrences. There is no single sampling frequency that meets all possible circumstances because the frequency is dependent upon local conditions and the proposed use of the data.

Sampling Duration

In consideration of this important parameter of sampling methodology it was necessary to sample over the entire duration of the storm due to the unpredictability of rainfall. The peak in flow may occur in the first hour of runoff or it may not occur until after several hours of low flow. If the quality of the runoff had been independent of the quantity, it would have been possible to discontinue sampling at some point of the storm after peak concentrations occurred and stable conditions returned. In other words, if the quality peaked with initial flow and declined steadily to a constant value, it would have been of little value to continue sampling. However, because the quality was found to be dependent on the quantity, especially for suspended solids, it was impossible to stop sampling until it was known that peak flow had occurred and rain had stopped.

Another factor which has to be considered is the fact that the mass emission rate of pollutants is highly dependent on volume of flow. The pounds of pollutant were almost directly related to the volume of flow; therefore, if one was concerned with 90 percent of the total mass emission of a particular pollutant it was necessary to wait until 90 percent of the runoff had occurred before sampling could be stopped. It was impossible to determine when 90 percent of the runoff had occurred until several weeks after the storm due to the nature of the flow recording instruments. The only way to determine when to stop sampling is by visual observations of weather and flow conditions at the respective sampling stations.

CONCLUSIONS

1. The Sentry automatic sequential composite sampler used in this study was entirely adequate for obtaining samples of stormwater runoff.
2. The pollutional characteristics of stormwater runoff for the two test watersheds (urban and semi-urban/rural) were not the same.
3. The peak BOD concentrations for the storms monitored at the urban and semi-urban/rural sampling stations ranged from 11.0 to 44.5 mg/l and from 3.0 to 7.0 mg/l, respectively.
4. The peak suspended solids concentrations for the storms monitored at the urban and semi-urban/rural sampling stations ranged from 62 to 250 mg/l and from 6 to 170 mg/l, respectively.
5. The total coliform counts for the runoff from the urban and semi-urban/rural watersheds for several storms ranged from 930 to 240,000 organisms/ml and from 930 to 46,000 organisms/ml, respectively.
6. The fecal coliform counts for the runoff from the urban and semi-urban/rural watershed for several storms ranged from 430 to 93,000 organisms/ml and from 930 to 9,300 organisms/ml, respectively.

7. A "first flush" of suspended solids and BOD was exhibited at the urban sampling station.
8. No "first flush" of BOD was apparent at the semi-urban/ rural sampling station and only a very small "first flush" of suspended solids was evident at this station.
9. Though "first flush" was evident, several subsequent flushes of suspended solids occurred after the initial flush when the flow increased dramatically. However, upon reaching maximum flow, solids concentration decreased and remained constant regardless of the flow pattern. This implies that minimum flow is required to completely flush the solids from the basin. The magnitude of this flow is dependent on the characteristics of the watershed and other parameters such as intensity of rainfall, duration of rainfall, antecedent dry period, etc.
10. The mass emission pollutographs of BOD and suspended solids were affected by both concentration and flow. The concentration affected the shape of the pollutograph while the flow affected both the shape and magnitude of the pollutograph. The flow hydrograph had a much more dramatic effect on the shape and magnitude of the pollutograph than did concentration.
11. The sampling procedure, which consisted of collecting a one liter sample once every half-hour, was totally adequate for the purposes of this study.

12. The sampling frequency had a measurable effect on the peak of the pollutograph. Decreasing the sampling frequency decreased the peak value by as much as forty percent. The sampling frequency had little effect on the shape of the curve except at peaks.
13. The unit "pounds per day per acre - MGD" permitted the comparison of the quality of stormwater runoff from the two test watersheds.
14. For all storms monitored, the stormwater runoff from the semi-urban/rural watershed had suspended solid and BOD values ranging from .14 to 4.3 lb/day/acre - MGD and from .07 to .14 lb/day/acre - MGD, respectively.
15. For all storms monitored, the stormwater runoff from the urban watershed had suspended solid and BOD values ranging from 7 to 24 lb/day/acre - MGD, and from 2 to 8 lb/day/acre - MGD, respectively.

RECOMMENDATIONS

1. In order to obtain the quality of "base" flow, periodic grab samples should be taken prior to a storm and after recession to "base" flow.
2. Further analyses should be performed in order to best characterize the quality of the stormwater runoff. Specifically, phosphate and nitrogen (NH_3, NO_2, NO_3) should be run in order to determine possible nutrient enrichment of stormwater retention facilities and/or ultimate receiving stream.
3. An investigation should be made of the possible correlation of pollutional parameters; particularly, the possible relationship between BOD in lb/day/acre - MGD and suspended solids in lb/day/acre - MGD. If such a correlation was found to exist, the required number of BOD analyses could be reduced in characterizing the quality of the stormwater runoff.
4. An investigation should be made to determine the possible existence of a minimum flow needed to "completely" flush and its possible relationship to rainfall intensity, rainfall duration, antecedent rainfall, and other factors.

5. The volume of sample should be increased from 1000 m/s to 1500 m/s, in order to have sufficient sample volume for proposed analysis. In order to achieve this, the present sampler will have to be adjusted so as to increase the pumping capacity.

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